ANALYSIS OF A METHODOLOGY

FOR LINEAR PROGRAMMING

OPTIMALITY ANALYSIS

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# ANALYSIS OF A METHODOLOGY FOR LINEAR PROGRAMMING OPTIMALITY ANALYSIS

**THESIS**

**Chanseok Jeong, Captain, ROKA**

**AFIT/GOR/ENS/97J-01**

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# ANALYSIS OF A METHODOLOGY FOR LINEAR PROGRAMMING OPTIMALITY ANALYSIS

THESIS

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**Chanseok Jeong, B.S.**
**Captain,ROKA**

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| COMMITEE : | NAME / DEPARTMENT | SIGNATURE |
|---|---|---|
| Advisor | Dr. Kenneth W. Bauer, Jr. Ph. D. / ENS<br>Professor of Operations Research | Kenneth W. Bauer Jr. |
| Advisor | Lt Col James T. Moore, Ph. D. / ENS<br>Associate Professor of Operations Research | James T. Moore |

# *Preface*

This thesis is an extension of Osman Iyde's thesis, *Right-Hand-Side Multidimensionnal Optimality Analysis of a Large Scale Linear Program Using Metamodelling Techniques*, AFIT/GOR/ENS/95M-13, 1995 (1). His thesis employs the application of the methodology developed by Johnson, Bauer, Moore, and Grant to a large scale linear programming (LP) model, specifically Air Mobility Command's (AMC's) Strategic Transport Optimal Routing Model (STORM).

I expand the scope of Iyde's work. His work was based on changing the right-hand-side (RHS) vectors, but I changed not only the RHS vectors but also the unit cost vector. I also refined the geographical areas and added the C-17 aircraft to the analysis, and I used a "Hot Start" idea for efficient solving of the experimental design runs of STORM.

In this thesis, the Strategic Transport Optimal Routing Model was chosen as a large scale linear program (LP). STORM is based on a model built by Barton and Guiriaer (1967) for Lockheed to analyze the peacetime employment of the new C-5 cargo plane.

I used the response surface methodology (RSM) developed by Myers and Montgomery and "Metamodelling Techniques in Multidimensional Optimality Analysis for Linear Programming" developed by Johnson, Bauer, Moore and Grant. This research basically accomplishes an optimality analysis for LP models by developing first or second order metamodels which describe the relationships among the optimal objective function value, and the right-hand-side (RHS) and unit cost vectors of LPs.

My research may help to analyze variable prediction when the resources of the channel cargo system are changed.

I appreciate my advisors Dr. Kenneth W. Bauer and Lt Col James T. Moore for their good guidance and advice. I would also like to thank my wife Enkyeong Yoon for her support and my two daughters Hyenjoo and Yeonjoo.

**Chanseok Jeong**

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## *Abstract*

The methodology of Johnson, Bauer, Moore, and Grant can be applied to large scale linear programming models. A methodology for optimality analysis of linear programs was developed to create metamodels using response surface methodology techniques such as experimental design and least squares regression. A metamodel consists of a simple equation which is able to predict the optimal objective function value of a linear program. What is needed is some large scale application of the techniques to verify how accurate they are.

In the research, I plan to use the large scale LP model, STORM. I use the "Hot Start" idea for the efficiency of STORM program calculation. The developed metamodels of the large scale LP can provide some useful information about the relationships between the objective function value and the right-hand-side vector and coefficients of the objective function (unit cost vector) by varying the right-hand-side vector and unit cost vector.

## *ANALYSIS OF A METHODOLOGY FOR LINEAR PROGRAMMING OPTIMALITY ANALYSIS*

# *I. INTRODUCTION*

This thesis is an extension of Osman Iyde's thesis, *Right-Hand-Side Multidimensionnal Optimality Analysis of a Large Scale Linear Program Using Metamodelling Techniques*, AFIT/GOR/ENS/95M-13, 1995 (1). His thesis employs the application of the methodology developed by Johnson, Bauer, Moore, and Grant (7) to a large scale linear programming (LP) model, specifically Air Mobility Command's (AMC's) Strategic Transport Optimal Routing Model (STORM). The methodology of Johnson, *et al.* utilizes response surface methology and kriging. It basically accomplishes an optimality analysis for LP models by developing first or second order metamodels which describe the relationships between the optimal objective function value and the right-hand-side (RHS) vectors of the LPs (7:45).

This thesis also applies response surface methodology and metamodeling techniques in multidimensional optimality analysis to a large scale linear programming model, AMC's STORM. However, I expand the scope of Iyde's work. His work was based on changing the RHS vectors, but my research accomplishes an optimality analysis for large scale LP models by developing metamodels which describe the relationships between the optimal objective function value and the RHS as well as the unit cost vector.

I changed not only the RHS vectors but also the unit cost vector. I also refined the geographical areas and added the C-17 aircraft to the analysis, and I used the "Hot Start" technique for making the STORM runs required by the experimental design.

### *1.1 Background*

In this thesis, STORM was chosen as a large scale linear program (LP) for the application of response surface methodology (RSM). The Strategic Transport Optimal Routing Model (STORM) is based on a model built by Barton and Guiriaer (1967) of Lockheed to analyze the peacetime employment of the new C-5 cargo plane. STORM was developed at Air Mobility Command (then the Military Aircraft Command) to assist in a major study of the entire scheduled cargo system that must provide two main types of service to its overseas customers. The first is to provide sufficient cargo capacity for a given period of time (usually for one month) to meet all demands for cargo movement between the pairs of bases in the system. This cargo capacity is known as the cargo requirement. The second is to provide a minimum number of flights per month between certain cities. This number is called the frequency requirement. The basic purpose of STORM is to select the mix of routes and aircraft that will meet the monthly cargo and frequency requirements of AMC while minimizing the cost of cargo handling, military aircraft operations, and commercial aircraft leasing (9:2).

The set of routes, maximum payload, and total flying hours for each type of plane are the main resources available. Using this information, STORM constructs a feasible cargo movement plan. A route is the sequence of legs to be flown by a single aircraft. Each aircraft's maximum payload

is an average based on the fuel loads and types of palletized cargo that are generally carried on the planned missions.

The flying hour limit for military aircraft is derived from the Air Force flying program which is necessary to maintain proficiency in worldwide operations and to train the crews. Versions of STORM for UNIX Workstations have been developed using the GAMS (General Algebraic Modeling System) modeling language (2) which makes data management and programming very easy. GAMS also allows the analyst to modify the model quickly for specific analyses, investigating specific questions, or enforcing operational considerations locally.

One methodology for optimality analysis of linear programs was to create metamodels using response surface methodology techniques such as experimental design and least squares regression. Metamodels have the form of a simple polynomial, and they predict the optimal objective function value of an LP for various levels of the constraints.

The developed metamodels of the large scale LP can provide some useful information about the relationships among the objective function value and unit cost and RHS vectors of interest.

The RHS and unit cost vectors of an LP may be changed for a variety of reasons: we may want to conduct a sensitivity analysis to check the preciseness of the RHS and unit cost vectors, and whether or not it matters if the RHS and unit cost vectors are perturbed. Also, we may want to update the LP when additional (reduced) resources become available (unavailable).

In this case, optimality analysis comes into play. Optimality analysis is performed to determine the effect on the optimal solution when the right-hand-side vector or the objective function coefficient vector is changed. Optimality analysis generally involves multiple critical regions with different optimal bases.

Before accomplishing the optimality analysis of the large scale LP model, I developed an alternative programing and solution technique which is called "Hot Start" method to reduce the total running time of a large scale LP model since multiple solutions of the LP model are required to develope the metamodels.

## *1.2 Research Objectives*

I employed the large scale LP model, STORM, and varied the right-hand-side vector and unit cost vector. For the multidimentional optimality analysis, I used the metamodelling techniques developed by Johnson, Bauer, Moore and Grant. I constructed the metamodels for objective function values which are the minimum cost values obtained by changing the levels of the RHS and unit cost vectors.

By using that methodology, the objectives are to analyze the accuracy of the metamodels and to describe the key relationships among the optimal objective function value, the unit cost vectors, and the right-hand-side vectors of interest. It is possible to predict the response of the optimal objective function value easily and efficiently when the levels of the factors are changed.

In the research, I use an idea called a "Hot Start" in solving the STORM program. "Hot Start" is a method that takes advantage of a "good" starting solution (12:115). I try to create metamodels with only first order polynomials by changing the level of RHS and unit cost vectors, up and down 10%. I apply $2^k$ factorial designs and $2^{k-p}$ fractional factorial designs to create metamodels by least square regression.

Two primary measures are used: mean squared error (MSE) and mean absolute percentage error (MAPE).

# *II. LITERATURE REVIEW*

This chapter presents a literature review about linear programming and metamodeling techniques in multidimensional optimality analysis. I apply this technique to a large scale linear programming model, AMC's STORM.

## *2.1 General theorem of linear programming*

Linear programming is concerned with the optimization (minimization or maximization) of a linear function while satisfying a set of linear equality and/or inequality constraints or restrictions.

### *2.1.1 Basic Definitions*

Any general linear programming problem may be manipulated into this form.

$$
\begin{array}{llllllll}
\text{Minimize} & c_1x_1 & + & c_2x_2 & + & \cdots\cdots & + \, c_nx_n & \\
\text{Subject to} & a_{11}x_1 & + & a_{12}x_2 & + & \cdots\cdots & + \, a_{1n}x_n & \geq \; b_1 \\
 & a_{21}x_2 & + & a_{22}x_2 & + & \cdots\cdots & + \, a_{2n}x_n & \geq \; b_2 \\
 & \vdots & & \vdots & & & \vdots & \;\; \vdots \\
 & a_{m1}x_2 & + & a_{m2}x_2 & + & \cdots\cdots & + \, a_{mn}x_n & \geq \; b_m \\
 & x_1, & & x_2, & & \cdots\cdots, & x_n & \geq \; 0
\end{array}
$$

Here $c_1x_1 + c_2x_2 + \ldots + c_nx_n$ is the *objective function* to be minimized and it is denoted by $z$. The coefficients $c_1, c_2, \ldots, c_n$, are the (known) *cost coefficients and* $x_1, x_2, \ldots, x_n$, are the *decision variables* (variables, structural variables, or activity levels) to be determined. The inequality $\Sigma^n_{j=1} a_{ij}x_j \geq b_i$ denotes the *i*th *constraint* (restriction or functional, structural, or technological constraint). The coefficients $a_{ij}$ for $i = 1, 2, \ldots, m$, $j = 1,2, \ldots, n$ are called the *technological coefficients.* These technological coefficients form the *constraint matrix* **A**.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & \cdots\cdots & a_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{m1} & a_{m2} & \cdots\cdots & a_{mn} \end{bmatrix}$$

The column vector whose *i*th component is $b_i$, which is referred to as the *right-hand-side vector,* represents the minimal requirements to be satisfied. The constraints $x_1, x_2, \ldots, x_n \geq 0$ are the *nonnegativity restrictions.* A set of variables $x_1, x_2, \ldots, x_n$ satisfying all the constraints is called a *feasible point* or a *feasible vector.* The set of all such points constitutes the *feasible region* or the *feasible space.*

Using the foregoing terminology, the linear programming problem can be stated as follows: Among all feasible vectors, find one that minimizes (or maximizes) the objective function (5:1-2).

### *2.1.2 Geometric solution*

This section describes a geometric procedure for solving a linear programming problem.

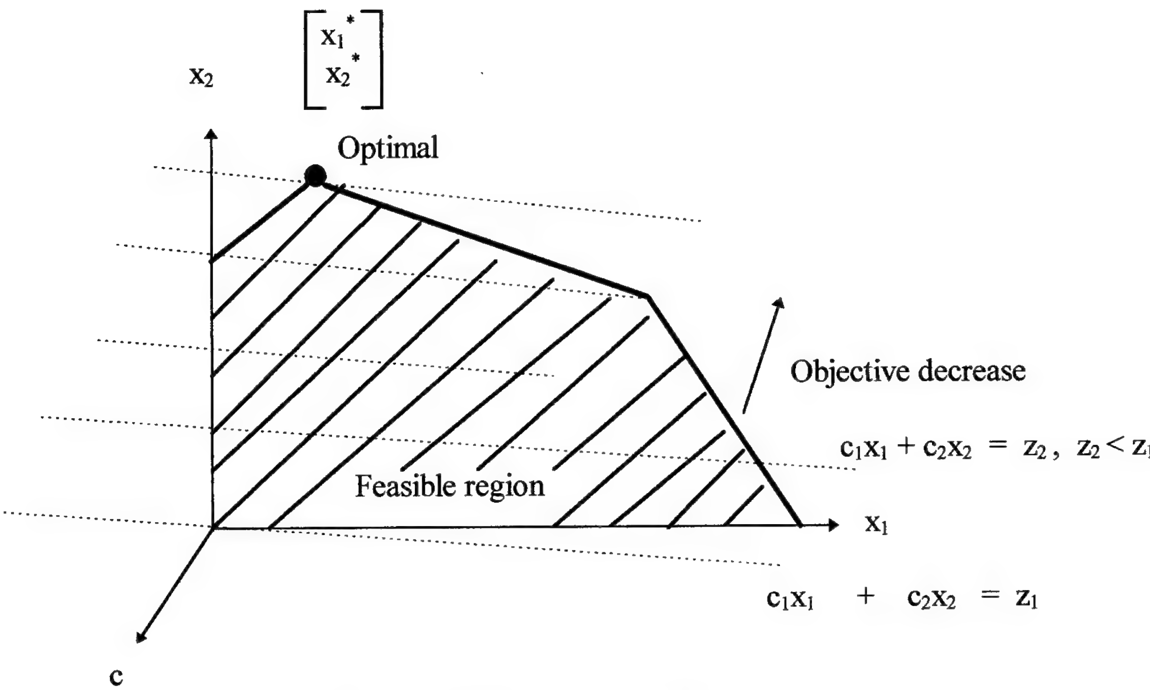


**Figure 2.1 Geometric solution**

The geometric solution provides a great deal of insight into the linear programming problem. To be more specific, let us consider the following problem.

$$\begin{aligned} &\text{Minimize} && \mathbf{cx} \\ &\text{Subject to} && \mathbf{Ax} \geq \mathbf{b} \\ & && \mathbf{x} \geq \mathbf{0} \end{aligned}$$

The feasible region consists of all vectors $\mathbf{x}$ satisfying $\mathbf{Ax} \geq \mathbf{b}$ and $\mathbf{x} \geq \mathbf{0}$. Among all such points we wish to find a point with minimal $\mathbf{cx}$ value. Points with the same objective function value $z$ satisfy the equation $\mathbf{cx} = z$, that is, $\Sigma^n_{j=1} c_j x_j = z$. Since $z$ is to be minimized, then the plane (line in a two-dimensional space) $\Sigma^n_{j=1} c_j x_j = z$ must be moved parallel to itself in the

direction that minimizes the objective most. This direction is - **c**, and hence the plane is moved in the direction - **c** as much as possible. This process is illustrated in Figure 2.1.

As the optimal point x* is reached, the line $c_1x_1 + c_2x_2 = z^*$, where $z^* = c_1x_1^* + c_2x_2^*$, cannot be moved farther in the direction $-\mathbf{c} = (-c_1, -c_2)$ because this leads to points outside the feasible region. In other words, one cannot move from **x*** in a direction that makes an acute angle with - **c** and hence reduces the objective function value while remaining feasible. So, **x*** is indeed the optimal solution (5:15).

### *2.1.3 Optimality*

Given a basic feasible solution $\mathbf{x_B} = \mathbf{B}^{-1}\mathbf{b}$, where **B** is a nonsingular $m \times m$ submatrix of **A**, with $z_0 = \mathbf{c_B x_B}$ for the LP $\mathbf{Ax} = \mathbf{b}$, $\mathbf{x} \geq \mathbf{0}$, $min\ z = \mathbf{cx}$. If $z_j - c_j \leq 0$ for every column $\mathbf{a}_j$ in **A** where $z_j = \mathbf{c_B B}^{-1}\mathbf{a}_j$, then $z_0$ is the minimum value of $z$ subject to the constraints, and the basic feasible solution is an optimal basic feasible solution (8:97).

## *2.2 Response Surface Methodology*

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs (6:1).

### 2.2.1 *Approximating Response Functions*

In general, suppose that the scientist or engineer is concerned with a product, process, or system involving a response $Y$ that depends on the controllable input variables $\xi_1$ , $\xi_2$ , ..., $\xi_n$. The relationship is

$$Y = f(\xi_1, \xi_2, \ldots, \xi_n) + \varepsilon \qquad (2.1)$$

where the form of the true response function $f$ is unknown and perhaps very complicated, and $\varepsilon$ is a term that represents other sources of variability not accounted for in $f$. Thus $\varepsilon$ includes effects such as measurement error on the response, other sources of variation that are inherent in the process or system (background noise, or common cause variation in the language of statistical process control), the effect of other variables, and so on. $\varepsilon$ is treated as a statistical error, where it is often assumed that $\varepsilon$ has a normal distribution with mean zero and variance $\sigma^2$. If the mean of $\varepsilon$ is zero, then

$$E(Y) = \eta = E[f(\xi_1, \xi_2, \ldots, \xi_n)] + E(\varepsilon)$$

$$\eta = f(\xi_1, \xi_2, \ldots, \xi_n) \qquad (2.2)$$

The variables $\xi_1$ , $\xi_2$ ,....., $\xi_n$ in Equation (2.2) are usually called the **natural variables,** because they are expressed in the natural units of measurement. In much RSM work it is convenient to transform the natural variables to **coded variables** $x_1$ , $x_2$ ,....., $x_n$, where these

coded variables are usually defined to be dimensionless with mean zero. In terms of the coded variables, the true response function (2.2) is now written as

$$\eta = E(Y) = f(x_1, x_2, \ldots\ldots, x_n) \tag{2.3}$$

Because the form of the true response function $f$ is unknown, we must approximate it. In fact, successful use of RSM is critically dependent upon the experimenter's ability to develop a suitable approximation for $f$. Usually, a low-order polynomial in some relatively small region of the independent variable space is appropriate. In many cases, either a **first-order** or a **second-order** model is used. For the case of $n$ independent variables, the first-order model in terms of the coded variables is

$$E(Y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_n x_n \tag{2.4}$$

The second-order model is widely used in response surface methodology for several reasons. The second-order model is very flexible. It can take on a wide variety of functional forms, so it often works well as an approximation to the true response surface. Also it is easy to estimate the parameters (the $\beta$'s) in the second-order model. The method of least squares can be used for this purpose. There is considerable practical experience indicating that second-order models work well in approximating true response surfaces (6:4-7).

In general, the second-order model is

$$E(Y) = \beta_0 + \sum_{j=1}^{n} \beta_j x_j + \sum_{j=1}^{n} \beta_{jj} x_j^2 + \sum\sum_{i<j} \beta_{ij} x_i x_j \tag{2.5}$$

### *2.2.2 Linear regression*

In the practical application of response surface methodology, it is necessary to develop an approximating model for the true response surface. The underlying true response surface is typically driven by some unknown **physical mechanism.** The approximating model is based on observed data from the process or system and is an **empirical model.** Multiple regression is a collection of statistical techniques useful for building the types of empirical models required in response surface methodology (6:16).

Equation (2.4) may be written in matrix notation as

$$\mathbf{Y} = \mathbf{X}\,\beta + \varepsilon \tag{2.6}$$

where

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ y_m \end{bmatrix} \qquad \mathbf{X} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1n} \\ 1 & x_{21} & x_{22} & \cdots & x_{2n} \\ & . & . & & . \\ & . & . & & . \\ & . & . & & . \\ 1 & x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \cdot \\ \cdot \\ \beta_n \end{bmatrix} \qquad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \varepsilon_m \end{bmatrix}$$

In general, $\mathbf{Y}$ is an $( m \times 1 )$ vector of the observations, $\mathbf{X}$ is an $( m \times p$ where $p = n + 1)$ matrix of the levels of the independent variables, $\beta$ is a $( p \times 1 )$ vector of the regression coefficients, and $\varepsilon$ is an $( m \times 1 )$ vector of random errors.

The method of least squares chooses the $\beta$'s in Equation (2.6) so that the sum of the squares of the errors, $\varepsilon_i$, are minimized. The least squares function is:

$$L = \sum_{i=1}^{m} \varepsilon_i^2 = \varepsilon'\varepsilon = ( \mathbf{Y} - \mathbf{X}\beta )' ( \mathbf{Y} - \mathbf{X}\beta )$$

$$= \mathbf{Y'Y} - \beta'\mathbf{X'Y} - \mathbf{Y'X}\beta + \beta'\mathbf{X'X}\beta$$

$$= \mathbf{Y'Y} - 2\beta'\mathbf{X'Y} + \beta'\mathbf{X'X}\beta \qquad (2.7)$$

Since $\beta'\mathbf{X'Y}$ is a $(1 \times 1)$ matrix, or a scalar, and its transpose $(\beta'\mathbf{X'Y})' = \mathbf{Y'X}\beta$ is the same scalar. The least squares estimators must satisfy:

$$\left.\frac{\delta L}{\delta \beta}\right|_{\mathbf{b}} = -2\mathbf{X'Y} + 2\mathbf{X'Xb} = \mathbf{0}$$

$$\mathbf{X'Xb} = \mathbf{X'Y} \tag{2.8}$$

To solve the normal equations, multiply both sides of Equation (2.8) by the inverse of **X′X.** Thus, the least squares estimator of $\beta$ is

$$\mathbf{b} = \hat{\beta} = (\mathbf{X'X})^{-1}\mathbf{X'Y} \tag{2.9}$$

The fitted regression model is

$$\hat{\mathbf{Y}} = \mathbf{Xb} \tag{2.10}$$

And the $(m \times 1)$ vector of residuals is denoted by

$$\mathbf{e} = \mathbf{Y} - \hat{\mathbf{Y}} \tag{2.11}$$

### *2.2.3 Experimental design*

Montgomery (14:27) defines experimental design as "a process of inducing purposeful changes in the input variable(s) in order to observe and model the changes in the response(s)."

The general problem of experimental design in response surface methodology is to choose a design such that the assumed polynomial that is fitted by the least squares regression most closely represents the true function over the factor space of interest. Experimental designs are selected

so that the experimental error is minimized or the bias due to the model misspecification is minimized.

Factorial designs are widely used in experiments involving several factors where it is necessary to investigate the joint effects of the factors on a response variable. By joint factor effects, we typically mean main effects and interactions. A very important special case of the factorial design is that where each of the k factors of interest has only two levels. Because each replicate of such a design has exactly $2^k$ experimental trials or runs, these designs are usually called $2^k$ factorial designs.

The class of $2^k$ factorial designs are very important in response surface work. Specifically, they find applications in three areas: 1) A $2^k$ design is useful at the start of a response surface study where screening experiments should be performed to identify the important process or system variables. 2) A $2^k$ design is often used to fit a first-order response surface model and to generate the factor effect estimates required to perform the method of steepest ascent. 3) The $2^k$ design is a basic building block used to create other response surface designs (6:79).

If the experimenter can reasonably assume that certain high-order interactions are negligible, then information on the main effects and low-order interactions may be obtained by running only a fraction of the complete factorial experiment. These fractional factorial designs are the most widely used types of design.

A major use of fractional factorials is in screening experiments. These are experiments in which many factors are considered with the purpose of identifying those factors (if any) that have large effects. Screening experiments are usually performed early in a response surface study when it is likely that many of the factors initially considered have little or no effect on the response. The

factors that are identified as important are then investigated more thoroughly in subsequent experiments (6:134).

### *2.2.4 GAMS language*

Substantial progress was made in the 1950s and 1960s with the development of algorithms and computer codes to solve large mathematical programming problems. The number of applications of these tools in the 1970s was less than expected, however, because the solution procedures formed only a small part of the overall modeling effort. A large part of the time required to develop a model involved data preparation and transformation and report preparation. Each model required many hours of analyst and programming time to, organize the data and write the programs that would transform the data into the form required by the mathematical programming optimizers. Furthermore, it was difficult to detect and eliminate errors because the programs that performed the data operations were only accessible to the specialist who wrote them and not to the analysts in charge of the project.

GAMS was developed to improve on this situation by

- o Providing a high-level language for the compact representation of large and complex models
- o Allowing changes to be made in model specifications simply and safely
- o Allowing unambiguous statements of algebraic relationships
- o Permitting model descriptions that are independent of solution algorithms

The design of GAMS has incorporated ideas drawn from relational database theory and mathematical programming and has attempted to merge these ideas to suit the needs of strategic modelers. Relational databases provide a structured framework for developing general data organization and transformation capabilities. Mathematical programming provides a way of describing a problem and a variety of methods for solving it (2:3).

### *2.2.5 Metamodelling methodology*

Response surface methodology (RSM) and kriging are used to develop a methodology for optimality analysis of linear programs (LPs). Using these techniques, metamodels are developed to predict the optimal objective function value of an LP for various levels of the constraints. These metamodels are valid over multiple critical regions, eliminating the usual requirement of determining which critical region contains the right-hand-side vector of interest. The metamodels are used to determine the responsiveness of the optimal objective function value to changes in the right-hand-side vector while illuminating key relationships between the objective function value and the elements of the right-hand-side vector. In some cases, the metamodels can actually be used as a surrogate model for the entire LP model. The metamodels are tested by comparing the predictions to the optimal solutions obtained by solving the linear programming model.

This metodology uses the phrase "optimality analysis" to refer to analyses of the optimal solution when the right-hand-side vector (or objective function coefficient vector) is changed. These analyses often involve multiple critical regions with different optimal bases. In contrast, "postoptimality analysis" and "sensitivity analysis" refer to analyses within a single critical region involving perturbations away from an initial solution (7:45).

## 2.3 Conclusion

This chapter presents a literature review on linear programming and the technique which I selected for study, "Metamodeling Techniques in Multidimensional Optimality Analysis" by Johnson, Bauer, Moore, Grant. For optimality analysis, metamodels are developed using experimental design and least squares regression.

# *III. METHODOLOGY*

This chapter presents two methodologies. One is how to "Hot Start" and the other is how to apply the metamodelling techniques for the large scale linear programming model.

## *3.1 "Hot Start" techniques for the STORM model*

A "Hot Start" is a technique designed to take advantage of a "good" starting solution (12:115) when solving an LP. The sequence of "Hot Start" when producing solutions for use in metamodel development depends on the number of changing factor levels in the experimental design. Before the presentation of "Hot Start" techniques, we need to know the detailed elements of the STORM model.

### *Required elements for the STORM model*

The STORM model requires some elements which are described as follows:

1. Aircraft Routes and Flying Times: Possible cargo routes must be specified for the STORM model in advance, along with flying times for each type of plane on each route.
2. Aircraft Data: Information specific to each aircraft type, such as payload, total number of flying hours available, and cost per operating hour. Aircraft include commercial cargo planes (Boeing 747, DC-8, and DC-10) as well as AMC military aircraft (C-5, C-17, C-141, and C-130).
3. Cargo and Frequency Requirements: The number of missions to be flown is based upon the need to move aircraft and cargo between certain pairs of bases. Cargo tonnage, frequency requirements, and possible transshipment points must be specified for each pair of bases.

4. Cargo Handling Costs: The STORM model allows cargo to move either by a direct flight or by a flight with one transshipment. Each time cargo is loaded or unloaded, a handling cost of $176 per ton is incurred.

5. Base Operating Limits: If any base in the system has restrictions on the maximum number of channel flights it can handle in a month, this value must be specified.

The STORM model uses the preceding information to formulate a linear programming model which can best be described as follows:

MINIMIZE : Total cost incurred for aircraft operating hours and cargo handling.

***SUBJECT TO:***

1. Meeting as many of the cargo movement requirements as possible.
2. Meeting all requirements for service frequency.
3. Operating within each aircraft type's flying hour and payload limits.
4. Operating within each base's limit on monthly sorties.

***Outputs of the model include:***

1. The number of missions flown on each route by each aircraft type.
2. The number of tons that could not be delivered for each origin/destination pair. Since STORM allows only one transshipment for each piece of cargo, many of these undelivered requirements can be met with two transshipments.
3. For each movement requirement, the tonnage delivered directly by a single mission.

4. For each movement requirement, the tonnage transshipped through each possible transshipment point.
5. The percentage of available cargo space utilized on each leg of each route.

The linear programming formulation used in STORM has been implemented in the LP modeling language GAMS. GAMS can use a wide variety of LP solvers and machines, and it greatly decreases the time involved in formulating, testing, and debugging models, as well as providing an excellent report writing capability. The description given below is designed to aid in interpreting the GAMS program listing.

There are six types of variables that are used in the STORM LP model of the channel cargo system. They are as follows:

1. Y(c,cd): The number of tons of cargo from source base 'c' which cannot be delivered to final destination bases 'cd'.
2. X(routes, aircraft): The number of missions to be flown on a route by aircraft type.
3. D(routes, stp, st2): The number of tons of cargo to be delivered directly from stop number 'stp' of the route (its origin) to stop number 'st2' of the route (its destination).
4. S(routes, stp, st2): The number of tons picked up at a transshipment point (stop number 'stp' of the route) and delivered to its final destination (stop number 'st2').
5. T(routes, stp, st2, cd):The number of tons picked up at a route origin ('stp') and dropped off at a transshipment point ('st2') for eventual delivery to its final destination base 'cd'.
6. SLK(routes, stp): The unused cargo capacity on the 'stp'th leg of the route.

Generating variables for all combinations of routes, bases and aircraft types would yield an unmanageable number of redundant and unnecessary variables in the LP formulation. To prevent this, a FORTRAN program examines the set of routes, transshipment points, and cargo requirements and builds only those combinations required for the current data. A FORTRAN program builds a number of data sets which are used as "INCLUDE" input files in the GAMS program. The created files have extensions. .TMP and .VAR.

There are nine types of constraints in the model. They are listed below by their GAMS names and described briefly:

1. TREQ(c, cd): Total tonnage to be moved from base 'c' to base 'cd' must equal the direct deliveries plus the transshipment deliveries plus the amount left undelivered.
2. CARGB(ct, cd): The amount of cargo being unloaded at base 'ct' for transshipment to base 'cd' must equal the amount being picked up at 'ct' for transshipment delivery to base 'cd'.
3. PL1(routes): Cargo carried on the first leg of a route cannot exceed the sum of the payloads of all aircraft flying that route.
4. PLP(routes, stp): Cargo loaded to fly leg 'stp' (*stp* > 1) cannot exceed the unused capacity on the previous leg plus the amount of cargo just unloaded.
5. ABAL(c, aircraft): At each base 'c' the number of landings by an aircraft type must equal the number of takeoffs by that type (conservation of flow).
6. FREQ(c, cd): The required minimum number of direct flights (i.e. the frequency requirement) from base 'c' to the base 'cd' must be attained.
7. UPHRS(aircraft): Maximum number of flying hours for each aircraft type must not be exceeded.

8. LOHRS(aircraft): Minimum number of flying hours for each aircraft type must be achieved.
9. MAXLND(c): The maximum allowable visits to a base ‘c’ must not be exceeded.

The objective function, COST, is the sum of (a) the cost of aircraft operating hours, (b) a surcharge of 79% on flying hours for each commercial mission that is bought one-way, (c) a handling charge for each time a ton of cargo is loaded or unloaded, and (d) a "penalty cost" of $10,000 per ton for failure to deliver cargo.

### *3.1.1 The problem of large scale linear programming*

Table 3.1 shows the minimum cost solution of a STORM formulation which has 7448 variables and 1833 equations. The LP poses computational challenges, requiring a long time to solve. The general solving time of STORM is 49 minutes on a VMS server and solution times may increase more than linearly with the number of nonzero variables.

**Table 3.1 Solved optimal value with normal RHS vectors**

| | | | |
|---|---|---|---|
| | S 0 L V E | S U M M A R Y | |
| MODEL | STORM1 | OBJECTIVE | Z |
| TYPE | LP | DIRECTION | MINIMIZE |
| SOLVER | ZOOM | FROM LINE | 10288 |
| SOLVER | STATUS | 1 NORMAL | COMPLETION |
| MODEL | STATUS | 1 OPTIMAL | |
| OBJECTIVE | VALUE | 37496750.1731 | |
| RESOURCE | USAGE, LIMIT | 915. 980 | 1000.000 |
| ITERATION | COUNT, LIMIT | 8641 | 40000 |

### *3.1.2 The methodology of "Hot Start" for reducing solving time*

Figure 3.1 shows the "Hot Start" methodology.

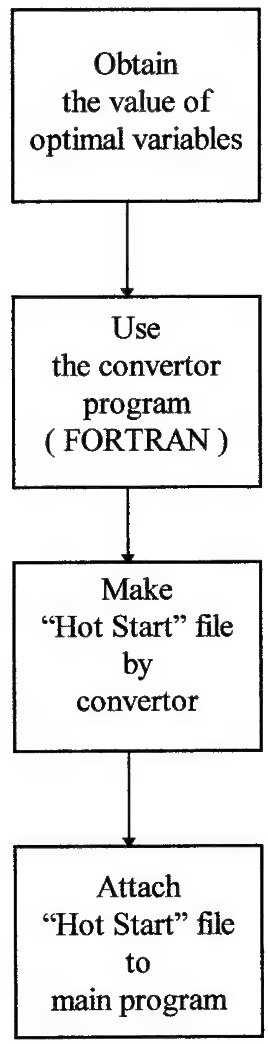


**Figure 3.1 the direction of "Hot start" methodology**

When GAMS calls a solver, the STORM decision variables start with a value of zero and in general 9000 iterations are required to find the optimal solution. Table 3.2 is a table of Y(c, cd)

values at optimality for various pairs of bases. If the basis of the previous optimal solution is used as the starting point for the next STORM model with changed RHS vectors, the solution time can be be reduced.

**Table 3.2 The optimal value table of Undelivered cargo [Y(c, cd)]**

| Origin \ Destination | EDAF | OBBI | OEDR | RODN |
|---|---|---|---|---|
| KDOV | | | | 8.87 |
| KSUU | | 0.04 | 0.02 | |
| RJTY | 0.28 | | | |

**<u>Air Base Decode</u>**

EDAF : Rhein-main AB, Germany
OBBI : Bahrain Intl, Bahrain
OEDR : Dhahran Intl, Saudi Arabia
RODN : Kadena AB, Japan
KDOV : Dover AFB, DE, U.S.A
KSUU : Fairfield/Travis AFB, CA, U.S.A
RJTY : Yokota, Japan

GAMS was designed with a database system in which records are maintained for the variables and equations. GAMS stores the optimal solution in records. There are four fields in each record:

.LO = lower bound

.L = level or primal value of variable

.UP = upper bound

.M = marginal or dual value of variable

By the use of the GAMS command, " .L ", a "Hot Start", which is shown in Table 3.3, is accomplished for the next LP.

There are many variables in this solution. Hence, a complete program was required to convert the file. To create the "Hot Start" file shown in Table 3.3, a convertor program is needed. The "Hot Start" file shown in Table 3.3 is created by using the convertor program shown in Appendix A and the optimal value file of the variables shown in Table 3.2. Table 3.3 is a partial example of a "Hot Start" file and the created file "YL.STM" is the data file for STORM.

**Table 3.3 "Hot start" file (YL.STM) for the next LP**

```
Y.L("KDOV","RODN") = 8.87;
Y.L("KSUU","OBBI") = 0.04;
Y.L("KSUU","OEDR") = 0.02;
Y.L("RJTY","EDAF") = 0.28;
```

In a similar fashion, five other program files for STORM, "XL.STM ", "DL.STM", "SL.STM", "TL.STM" and "SLKL.STM" are created. I present these files in Appendix B and all convertor programs which are written in FORTRAN are shown in Appendix A.

## *3.2 Response Surface Methodology for LP*

If the optimal objective function value is defined as the response, and the levels of the RHS vectors and the unit cost vectors are defined as predictors, Response Surface Methodology (RSM) can be applied to predict the optimal objective function value based on the values of the elements of the RHS and unit cost vectors.

Response Surface Methodology uses experimental design and least squares regression to develop a simple polynomial model, so RSM can be used to develop a methodology for optimality analysis of linear programs. Using these techniques, metamodels are developed to predict the optimal objective function value of a large scale LP for various levels of the constraints (7:45).

The methodology presented here uses RSM to develop a metamodel to describe the relationship between the levels of the constraints and the objective function value for an LP, and to predict the optimal objective function value for the LP given specific levels for the constraints. The RHS vectors for tonnage requirements and frequency requirement are changed up and down 10%, and the value of objective function coefficients are changed up and down 10 %. The reason 10% is selected as a changing level is to simplify the calculation and to easily understand the regression function.

I constructed six metamodels. In Metamodel 1, I simply choose two factors, tonnage requirement (**TREQ**) and frequency requirement (**FREQ**) because I want to start this research with a simple design. After analyzing Metamodel 1, I changed one more factor, the unit cost vector shown in Table 3.4, for Metamodel 2 which shows us the new relationship including the new factor. In Metamodels 3, 4, 5, I separate the factors of Metamodel 2 because I want to analyze each factor's geographical relationship with the objective function value in detail. In Metamodel 6, I integrated metamodel 4 and 5. It looks like metamodel 2 but the two factors in Metamodel 2 , **TREG** and **FREQ** are separated into five areas. This makes it possible to analyze the geographical relationships of these two factors with the objective function value and unit cost vector.

In Figure 3.2 the six  metamodels and their relationships are presented.

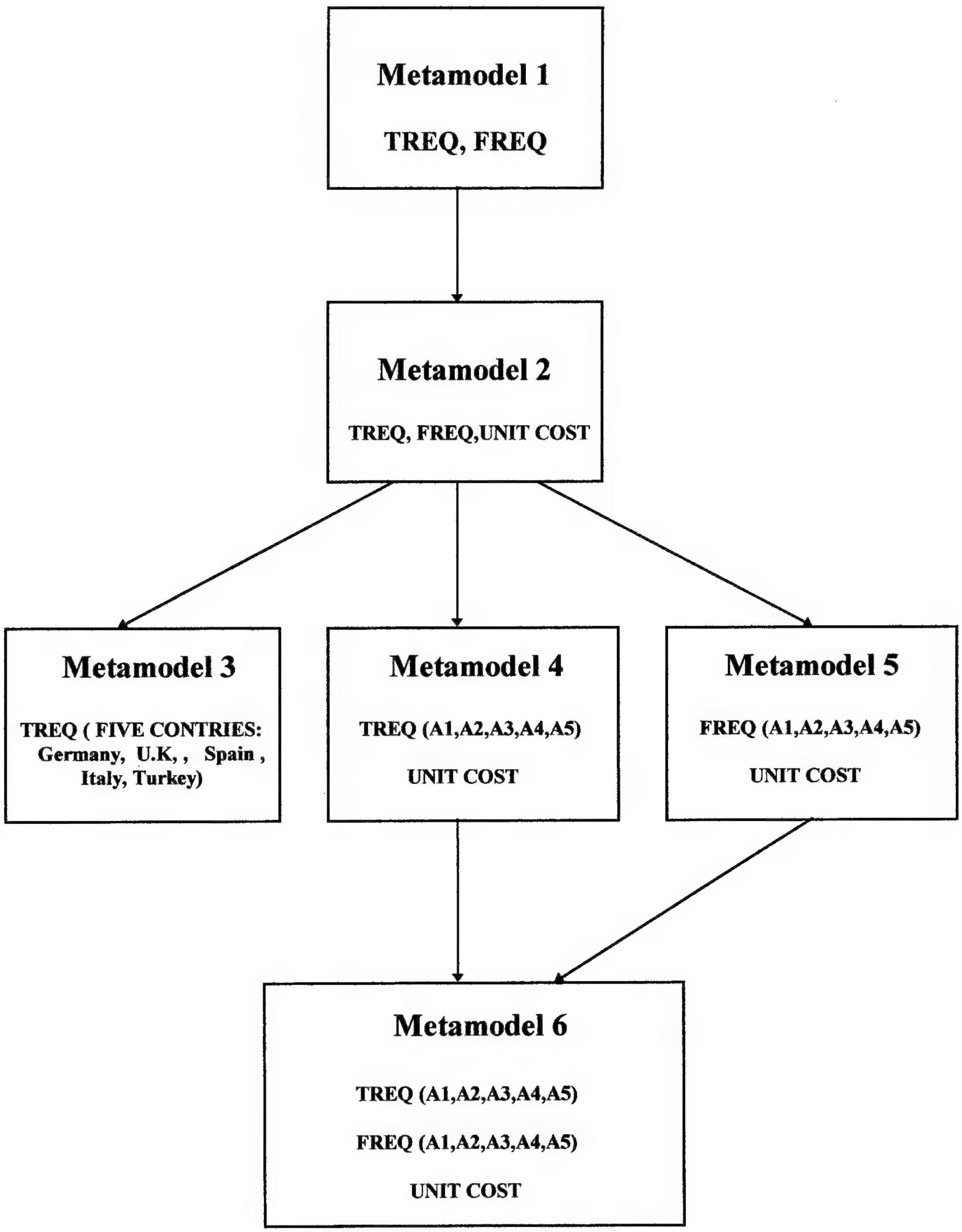


**Figure 3.2 The six  metamodels and the research directions**

**Metamodel 1** describes the relationship between the objective function value, tonnage requirement (**TREQ**) and frequency requirement (**FREQ**). The first factor, **TREQ,** is a $360 \times 1$ vector and the elements of the vector vary from 0.01 to 947.49 tons. The second factor, **FREQ,** is a $151 \times 1$ vector whose elements range from 1 to 24 visits per month between city pairs. In Metamodel 1, I use a $2^2$ factorial design and change the factors, **TREQ** and **FREQ** up and down 10%.

**Metamodel 2** describes the relationship between the objective function value, tonnage requirement, frequency requirement, and unit cost for each aircraft. I consider eight different types of aircraft ( C-5, C-141, C-130, B-747, DC-8, DC-10, KC-10, C-17). The three factors, **TREQ, FREQ** and **UNIT COST** are considered and I use a $2^3$ factorial design and change the cost factors shown in Table 3.4 up and down 10% and the **TREQ, FREQ** factors up and down 10%. Cost per hour by aircraft type is shown in Table 3.4.

**Table 3.4 Airplane cost per an hour (unit cost)**

| TYPE | COST($) |
|---|---|
| C005 | 7085 |
| C141 | 3320 |
| C130 | 2055 |
| B747 | 12011 |
| DC08 | 5519 |
| DC10 | 9980 |
| KC10 | 4750 |
| C017 | 3967 |

**Metamodel 3** explores the relationships between the minimum total cost (objective function value) and the tonnage requirement (**TREQ**) of five countries (**Germany, U.K, Spain, Italy, Turkey**) in Europe. Bosnia still continues its racial conflict and U.S troops serve as a member of NATO or U.N. in the European area. These are the reasons that I consider Europe as an important area for investigation. I use a $2^{5-1}$ fractional factorial design for this metamodel.

**Table 3.5 Five Areas in the AMC Channel System**

| Area | Region |
|---|---|
| 1 | North America including U.S.A. territories. |
| 2 | South America |
| 3 | Europe and North Africa. |
| 4 | East Asia. |
| 5 | Central Pacific and Middle East. |

**Metamodel 4** shows the relationships among the total cost (objective function value), the tonnage requirement (**TREQ**) and **UNIT COST** vectors of five areas which are shown in Table 3.5. The **Al, A2, A3, A4** and **A5** vectors for **TREQ** which correspond to areas 1, 2, 3, 4, and 5 were simply derived from the **TREQ** RHS vector by separating the elements of the **TREQ** vector into the related areas. These values are changed up and down 10%. I use a $2^{6-2}$ fractional factorial design for this metamodel.

**Metamodel 5** shows the relationships among the total cost (objective function value), the frequency requirement (**FREQ**) and **UNIT COST** vectors for the five areas shown in Table 3.5. I also construct a $2^{6-2}$ fractional factorial design for this metamodel.

**Metamodel 6** is a combination of **Metamodel 4** and **Metamodel 5** and it has a $2^{11-6}$ fractional factorial design.

### *3.2.1 Two-Level Factorial Designs*

Factorial designs used in this research involve several factors where it is desired to investigate the joint effects of the factors on a response variable. I employ $2^k$ factorial designs where each of the *k* factors of interest has only two levels for metamodels 1 and 2 which are shown in Table 3.6.

As the number of factors in a $2^k$ factorial design increase, the number of runs required for the complete replicate of the design rapidly outgrows the resources of most experimenters. If the experimenter can reasonably assume that certain high-order interactions are negligible, then information on the main effects and low-order interactions may be obtained by running only a fraction of the complete factorial experiment.

A design containing $2^{k-p}$ runs is called a $1/2^p$ fraction of the $2^k$ design or, more simply, a $2^{k-p}$ fractional design. These designs require the selection of $p$ independent design generations. A reasonable criterion is to select the generator such that the resulting $2^{k-p}$ design has the highest possible resolution. I used a two-level fractional factorial design for Metamodels 3, 4, 5 and 6.

**Table 3.6 Factorial Designs for metamodel**

| Metamodel | The component of Factors | Factorial Design |
|---|---|---|
| 1 | 2 factors (TREQ, FREQ) | $2^2$ Factorial Design |
| 2 | 3 factors (TREQ, FREQ, UNIT COST) | $2^3$ Factorial Design |
| 3 | 5 factors (TREQ:Germany, U.K, Spain, Italy, Turkey) | $2_V^{5-1}$ Fractional Factorial Design |
| 4 | 6 factors (TREQ: A1, A2, A3, A4, A5 and UNIT COST) | $2_{IV}^{6-2}$ Fractional Factorial Design |
| 5 | 6 factors (FREQ: A1, A2, A3, A4, A5 and UNIT COST) | $2_{IV}^{6-2}$ Fractional Factorial Design |
| 6 | 11 factors (TREQ: A1, A2, A3, A4, A5, FREQ: A1, A2, A3, A4, A5 and UNIT COST) | $2_{IV}^{11-6}$ Fractional Factorial Design |

After establishing the metamodel designs, the next step is to code the level of the constraints. Coding is achieved using a simple transformation given by

$$Z_i = \frac{b_i - b_{i,o}}{S_i} \tag{3.1}$$

where $b_i$ is the actual numerical level of the $i$th constraint. In this study, since we use two-level factorial designs, we can say that $b_i$ has $b_{i,max}$ and $b_{i,min}$ indicating the high and the low levels of

the constraints. Here $b_{i,o}$ is the midpoint between $b_{i,max}$ and $b_{i,min}$. If $S_i$ is taken to be $(b_{i,max} - b_{i,min}) / 2$, then $b_{i,max}$ and $b_{i,min}$ are mapped to 1 and -1, respectively (7:51).

The experimental designs used to develop the metamodels of interest in this research were determined according to the number of factors they were dealing with.

### *3.2.2 Least Squares Regression*

The experimental designs are selected so that the experimental error variance is minimized. We obtain our response by solving STORM for each design point. In this case, no experimental error is associated with the solution from the LP model. Since there is no experimental error, the purpose is to minimize the misspecification bias.

In this research, we approximate the LP model, specifically STORM, with a simple model. To achieve this, we apply least squares regression to the data obtained from the experimental design phase of the methodology of Johnson, et al. Let $\Phi$ denote the optimal objective function value as a function of the factors. Least squares regression develops an initial metamodel approximating $\Phi$ with a first order or second order polynomial since those types of polynomials are able to define some concave surfaces such as hyperplanes and domeshaped surfaces (7:52).

We can assume the functional relationship of the following form :

$$\mathbf{Y} = \mathbf{Z}\beta + \varepsilon \tag{3.2}$$

where

$$\mathbf{Y} = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_m \end{bmatrix} \qquad \mathbf{Z} = \begin{bmatrix} 1 & z_{11} & z_{12} & \cdots\cdots & z_{1n} \\ 1 & z_{21} & z_{22} & \cdots\cdots & z_{2n} \\ & \cdot & \cdot & & \cdot \\ & \cdot & \cdot & & \cdot \\ & \cdot & \cdot & & \cdot \\ 1 & z_{m1} & z_{m2} & \cdots\cdots & z_{mn} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \cdot \\ \cdot \\ \beta_n \end{bmatrix} \qquad \varepsilon = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \varepsilon_m \end{bmatrix}$$

We can compare Equation (3.2) with Equation (2.6) in Chapter II. They are similar except **X** is replaced by **Z** which is a matrix of coded values (1 or -1 obtained by Equation (3.1)). **Y** is an $m \times 1$ vector of known response values (in this case optimal objective function values obtained form STORM), **Z** is a $m \times p$ (where $p = n + 1$) matrix of the coded levels of the variables at the experimental design point, $\beta$ is a $p \times 1$ vector of coefficients, $\varepsilon$ is an $m \times 1$ vector of the random error, m is the number of data points, and p is the number of variables in the assumed function.

By the Equations (2.7) and (2.8) in Chapter II, the estimator of $\beta$ is

$$\hat{\beta} = (\mathbf{Z'Z})^{-1}\mathbf{Z'Y} \tag{3.3}$$

and the fitted regression model is

$$\hat{\mathbf{Y}} = \mathbf{Z}\hat{\beta} \tag{3.4}$$

### *3.2.3 Measuring the Performance of the Metamodels*

An accurate metamodel means a metamodel with a small residual. For example Metamodel 1 is validated by a $2^2$ full factorial design where the factors were coded at the (+0.5, -0.5) level (Perturbed by 5%). Figure 3.3 shows the test and validation design points on a coordinate axis. Note that the point (0,0) is the center point, for both designs.

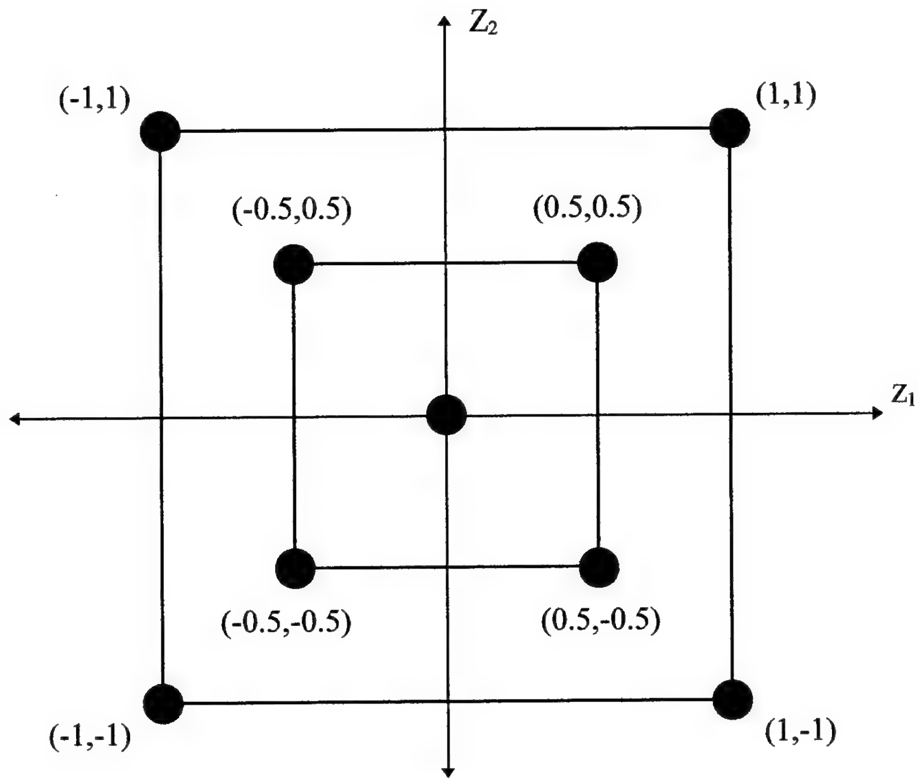


**Figure 3.3 Test and Validation Designs of Metamodel 1**

The predictions obtained from the regression metamodel are compared to the true optimal objective function values of the validation design by using some measures. In this research, two primary measures were used to evaluate the performance of the metamodels. The first is mean squared error (MSE) and the second is mean absolute percentage error (MAPE) (7:59).

Mean squared error (MSE) is a measure of accuracy computed by squaring the individual error for each item in the data set, and then finding the average or mean value of the sum of these squares. The mean squared error gives greater weight to large errors than to small errors since the errors are squared before being summed. MSE is defined by

$$MSE = \frac{\Sigma^{m}_{i=1} (\hat{Y}_i - Y^{V}_i)^2}{m} \qquad (3.5)$$

where $\hat{Y}_i$ is the predicted value of the objective function at the $i^{th}$ validation point ($Z = \pm 0.5$), m is the number of validation points and $Y^{V}_i$ is the true value of the objective function at the $i^{th}$ validation point (level changed up and down 5%).

Mean absolute percentage error (MAPE) is the mean or average of the sum of all of the percentage errors for a given data set taken without regard to sign. Thus, their absolute values are summed and the average computed. MAPE is given as follows:

$$\text{MAPE} = \frac{1}{m} \sum_{i=1}^{m} \left| \frac{(\hat{Y}_i - Y^v_i)}{Y^v_i} \right| \times 100 \qquad (3.6)$$

In this chapter, I have presented the STORM model and presented the foundation of six metamodels which are developed in depth in the next chapter.

# *IV RESULTS AND DISCUSSION*

This chapter presents the comparison between "Hot Start" results and non-"Hot Start" results and also shows the numerical results and their interpretations. In this research, six rnetamodels of STORM are developed to examine the applicability of the methodology of Johnson *et al.* which describe the relationship between the levels of the constraints and the objective function value for an LP, and predict the optimal objective function value for the LP given specific levels for the constraints. The level means the coded form of the factors, which are denoted by $Z_i$, $i = 1, \ldots, n$ in the following tables. The test metamodels are developed by changing the RHS and unit cost vectors by 10 percent ($\Delta = \pm 0.1$) and considering the five areas of AMC's channel system shown in Table 3.5.

The metamodels are given for the first order designs. Then, the results concerning their interpretations are presented.

## *4.1 Comparison results between "Hot Start" and non-"Hot Start"*

I selected Metamodel 1 as a sample model. In this model, I considered just two factors, tonnage requirement (TREQ) and frequency requirement (FREQ) which are changed up and down ten percent. There are six types of variables that are used in the STORM LP model of the channel cargo system. They are as follows:

Y(c,cd) : UNDELIVERED CARGO

X(routes,aircraft) : SORTIES ON A ROUTE BY AN AIRCRAFT TYPE

D(routes,stp,st2) : DIRECT DELIVERY CARGO

T(routes,stp,st2,cd) : FIRST PART OF TRANSSHIPMENT DELIVERY

S(routes,stp,st2) : SECOND PART OF TRANSSHIPMENT DELIVERY

SLK(routes,stp) : UNUSED CAPACITY ON EACH LEG OF EACH ROUTE

By the "Hot Start" method which I showed in Chapter III, I created six new files, LX.STM, YL.STM, DL.STM, SL.STM, TL.STM, and SLKL.STM which contain the "Hot Start" points of six types of variables. I attached these "Hot Start" files to the original STORM programming. I considered the number of iterations for the comparison because the computation time is different on different kinds of computers. The sequence of "Hot Start" depends on the fewest number of factor levels changing, so I take the sequence 1-2-4-3.treatment. The comparison is showed in Table 4.1 and Table 4.2 with the number of sequence and factor changes.

**Table 4.1 "Hot Start" comparison table for metamodel 1**

| Metamodel 1 | | | | | |
|---|---|---|---|---|---|
| **Treatment (Seq:Cha)** | **TREQ** | **FREQ** | **Non-"Hot Start"** | **"Hot Start"** | **Reduced ratio (%)** |
| **1(1:2)** | down 10% | down 10% | 7748 | 7042 | 9.11 |
| **2(2:1)** | down 10% | up 10% | 8667 | 7326 | 15.47 |
| **3(4:1)** | up 10% | down 10% | 10167 | 7400 | 27.21 |
| **4(3:1)** | up 10% | up 10% | 7476 | 6593 | 11.81 |
| **(Seq:Cha) :** (the number of sequence : the number of factor changes) | | | | | |

Table 4.2 "Hot Start" comparison table for metamodel 6

| Metamodel 6 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Treat-ment (Seq:Ch)** | **Non-Hot Start** | **Hot Start** | **Reduced ratio (%)** | **Treat-ment (Seq:Ch)** | **Non-Hot Start** | **Hot Start** | **Reduced ratio (%)** |
| 1**(1:11)** | 6028 | 7780 | 0 | 17**(18:5)** | 10313 | 10252 | 0.59 |
| 2**(3:4)** | 8134 | 7561 | 7.04 | 18**(20:6)** | 7743 | 8873 | 0 |
| 3**(2:5)** | 8437 | 8713 | 0 | 19**(17:7)** | 6963 | 8815 | 0 |
| 4**(4:5)** | 9680 | 7118 | 26.47 | 20**(19:4)** | 9550 | 9517 | 0.35 |
| 5**(6:4)** | 10686 | 8410 | 21.30 | 21**(22:7)** | 8623 | 8662 | 0 |
| 6**(7:7)** | 9577 | 9538 | 0.41 | 22**(21:5)** | 9717 | 8541 | 12.10 |
| 7**(8:4)** | 10857 | 8973 | 17.35 | 23**(23:5)** | 10499 | 7785 | 25.85 |
| 8**(5:5)** | 8899 | 6362 | 28.51 | 24**(24:7)** | 9105 | 8902 | 2.23 |
| 9**(11:4)** | 9205 | 7870 | 14.50 | 25**(25:7)** | 7583 | 9636 | 0 |
| 10**(9:7)** | 6354 | 8267 | 0 | 26**(28:5)** | 8861 | 8499 | 4.09 |
| 11**(12:5)** | 8823 | 8178 | 7.31 | 27**(26:5)** | 10404 | 10764 | 0 |
| 12**(10:5)** | 8243 | 8015 | 2.77 | 28**(27:5)** | 8801 | 9200 | 0 |
| 13**(13:6)** | 6950 | 9485 | 0 | 29**(29:4)** | 9116 | 8252 | 9.48 |
| 14**(15:5)** | 8577 | 10882 | 0 | 30**(32:4)** | 8351 | 9545 | 0 |
| 15**(16:4)** | 10138 | 8614 | 15.03 | 31**(31:7)** | 9051 | 10669 | 0 |
| 16**(14:4)** | 8867 | 8396 | 5.31 | 32**(30:4)** | 10328 | 7754 | 24.92 |
| **(Seq:Cha)** : (the number of sequence : the number of factor changes) | | | | | | | |

By comparing, I learn that reducing the solving time is possible by the "Hot Start" method and the efficiency of the "Hot Start" method for saving time is about 15.9% in Metamodel 1. I expect this method is helpful for models with more factor treatments, so I selected the most complicated metamodel which is Metamodel 6. I refered to Table 4.19 (page 55) for the sequence of selecting the treatment. When the number of factor changes is similar I give the priority to the treatment whose factor with the largest effect is not changed. I present the results in Table 4.2. They show a "Hot Start" efficiency of 7.1%. I attach a detailed comparison of the results in Appendix C.

## *4.2 The results of metamodels*

A methodology for optimality analysis of linear programs was developed to create metamodels using response surface methodology techniques such as experimental design and least squares regression. A metamodel consists of a simple equation, and it is possible to predict the optimal objective function value of a linear program using a metamodel.

I used the large scale LP, STORM, where the right-hand-side vectors and unit cost vectors can vary. By using the metamodels, I can describe the key relationships among the optimal objective function value and the right-hand-side vectors and unit cost vectors of interest.

It is possible to predict the response of the optimal objective function value easily and efficiently when the levels of factors are changed.

### *4.2.1 Metamodel 1*

Metamodel 1 describes the relationship between the objective function value, tonnage requirement (TREQ) and frequency requirement (FREQ). The first factor, TREQ, is a $360 \times 1$ vector and the elements of the vector vary from 0.01 to 947.49 tons. The second factor, FREQ, is a $151 \times 1$ vector whose elements range from 1 to 24 visits per month between city pairs. I used a $2^2$ factorial design and changed the factors up and down 10%. Metamodel 1 shows the effects of the factors, and in Table 4.3 factor A is Tonnage Requirement, factor B is Frequency Requirement, and Y is the optimal objective function value. Y is the minimum total cost of this LP.

The level of the factors are coded -1 and 1, and denoted by $Z_i$, $i = 1, \ldots, n$. In Table 4.3, the -1 and 1 represent levels of down 10% and up 10%, respectively.

In Table 4.4, the R-square is almost 1 and this means this model is a very accurate model. The original objective function value of STORM was \$37496750 which was shown in Table 3.1. By looking at the regression metamodel in Table 4.5, I can say that the contribution of the tonnage requirement to the predicted total flying cost is \$3395465 while it is \$457808 for the frequency requirement when the tonnage requirement vector and the frequency requirement vector are changed, up and down 10%. In other words, the tonnage requirement changes the total flying cost by 9.06% (\$3395465/\$37496750) while the frequency requirement changes the optimal objective function value by 1.22% (\$457808/\$37496750). Also, it is possible to say that regression Metamodel 1 estimates the total flying cost with an error of ±\$66096 for the design points included in the model.

**Table 4.3 Metamodel 1 : minimized-cost values for 4 treatments**

| Treatment | A | B | Y |
|---|---|---|---|
| 1 | -1 | -1 | 33644710.27 |
| 2 | -1 | 1 | 34692518.12 |
| 3 | 1 | -1 | 40567833.21 |
| 4 | 1 | 1 | 41351256.59 |

**Table 4.4 Metamodel 1 : Analysis of variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 2 | 4.6955092E13 | 2.3477546E13 | 1343.510 | 0.0193 |
| Error | 1 | 17474786995 | 17474786995 | | |
| C Total | 3 | 4.6972567E13 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 132192.2350 | R-square | 0.9996 |
| Dep Mean | 37564079.5475 | Adj R-sq | 0.9989 |
| C.V. | 0.3519 | | |

**Table 4.5 Metamodel 1 : Parameter estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37564080 | 66096.117502 | 568.325 | 0.0011 |
| A | 1 | 3395465 | 66096.117502 | 51.372 | 0.0124 |
| B | 1 | 457808 | 66096.117502 | 6.926 | 0.0913 |

$$\hat{Y} = 37564080 + 3395465\, Z_1 + 457808\, Z_2$$

**Table 4.6 Comparison with validation design for metamodel 1**

| Treatment | A | B | $Y^V$ | $\hat{Y}$ (Z = ±0.5) | $\lvert \hat{Y} - Y^V \rvert$ |
|---|---|---|---|---|---|
| 1 | -0.5 | -0.5 | 35570398.00 | 35637443.50 | 67045.50 |
| 2 | -0.5 | 0.5 | 36029101.77 | 36095251.50 | 66149.73 |
| 3 | 0.5 | -0.5 | 39006052.42 | 39032908.50 | 26856.08 |
| 4 | 0.5 | 0.5 | 39423802.92 | 39490716.50 | 66913.58 |
| **MSE** | | | | **MAPE** | |
| 3517390517.68 | | | | 0.152666889 | |

$\hat{Y}_i$ is the predicted value of the objective function at the i$^{th}$ validation point (Z = ±0.5), and. $Y^V$ is the true value of the objective function at the i$^{th}$ validation point (level changed up and down 5%).

I showed the validation design in Table 4.6, and Metamodel 1 was validated by a $2^2$ full factorial design where the factors were coded at the (+0.5, -0.5) level. The MSE and MAPE value indicate that metamodel 1 is a very acuurate model.

### *4.2.2 Metamodel 2*

Metamodel 2 examines the effects of the tonnage requirement, frequency requirement and unit cost. I plan to use a $2^3$ factorial design and change the three factors up and down 10%. In Table 4.7 factor A is Tonnage Requirement, factor B is Frequency Requirement and factor C is a 8 × 1 unit cost vector which is presented in Table 3.4.

By looking at the regression metamodel in Table 4.9, we can say that the contribution of the tonnage requirement to the total flying cost is $3395306 and it is $3384940 for unit cost vector while it is $457768 for the frequency requirement. In other words, the tonnage requirement changes the total flying cost by 9.05% and unit cost vector changes the total flying cost by 9.03% while the frequency requirement changes the optimal objective function value by 1.22%. I can see that unit cost factor is also a very important factor for the total flying cost and the ratios of tonnage requirement and the frequency requirement to the total flying cost is not changed when compared with metamodel 1. Metamodel 2 estimates the total flying cost with a standard error of ±$157092 which is more error than Metamodel 1 for the design points taken into account and this means Metamodel 2 is less accurate than Metamodel 1.

**Table 4.7 Metamodel 2 : minimized-cost values for 8 treatments**

| Treatment | A | B | C | Y |
|---|---|---|---|---|
| 1 | -1 | - 1 | -1 | 30614923.85 |
| 2 | -1 | -1 | 1 | 36674351.43 |
| 3 | -1 | 1 | -1 | 31559899.60 |
| 4 | -1 | 1 | 1 | 37825029.40 |
| 5 | 1 | -1 | -1 | 36916720.46 |
| 6 | 1 | -1 | 1 | 44218359.90 |
| 7 | 1 | 1 | -1 | 37624125.24 |
| 8 | 1 | 1 | 1 | 45077447.65 |

**Table 4.8 Metamodel 2 : Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 3 | 1.8556379E14 | 6.1854596E13 | 313.311 | 0.0001 |
| Error | 4 | 789689963271 | 197422490818 | | |
| C Total | 7 | 1.8635348E14 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 444322.5077 | R-square | 0.9958 |
| Dep Mean | 37563857.1913 | Adj R-sq | 0.9926 |
| C.V. | 1.1829 | | |

**Table 4.9 Metamodel 2 : Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37563857 | 157091.72910 | 239.121 | 0.0001 |
| A | 1 | 3395306 | 157091.72910 | 21.614 | 0.0001 |
| B | 1 | 457768 | 157091.72910 | 2.914 | 0.0435 |
| C | 1 | 3384940 | 157091.72910 | 21.548 | 0.0001 |

$$\hat{Y} = 37563857 + 3395306\ Z_1 + 457768\ Z_2 + 3384940\ Z_3$$

### *4.2.3 Metamodel 3*

This model investigates the effect of Germany, U.K, Spain, Italy and Turkey on the total flying cost. In Area 3, the RHS vectors of Germany, U.K, Spain, Italy and Turkey are changed when the other RHS vectors and unit cost vector keep their original values. I use $2^{5-1}$ fractional factorial design for this metamodel. Five countries are represented as A, B, C, D and E respectively, where A is a $28 \times 1$ RHS vector, B is a $10 \times 1$ RHS vector, C is a $18 \times 1$ RHS vector, D is a $17 \times 1$ and E is a $9 \times 1$ RHS vector. This metamodel can be called the regional search metamodel because it is trying to find the key relationships between the regions and the total cost in the dominating areas, namely Area 3 for the tonnage requirement.

When I look at the Table 4.11, I observe that $R^2$ is almost one showing that I have a good first order fit to the data. Also, the predicted optimal objective function values are close to the true optimal objective function values Y. In Table 4.12, I see that Germany is able to change the objective function value by 0.68% and this factor has the greatest impact in area 3. Germany, U.K and Turkey have big effects to the total flying cost while Spain and Italy have relatively small effects. Although U.K and Turkey have a smaller number of city pairs than Spain and Italy, they have more effect on the total flying cost.

**Table 4.10 Metamodel 3 : minimized-cost values for 16 treatments**

| Treatment | A | B | C | D | E | Y |
|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 1 | 37273226.27 |
| 2 | -1 | -1 | -1 | 1 | -1 | 37123725.85 |
| 3 | -1 | -1 | 1 | -1 | -1 | 37144297.18 |
| 4 | -1 | -1 | 1 | 1 | 1 | 37349846.12 |
| 5 | -1 | 1 | -1 | -1 | -1 | 37190794.19 |
| 6 | -1 | 1 | -1 | 1 | 1 | 37375698.52 |
| 7 | -1 | 1 | 1 | -1 | 1 | 37396327.75 |
| 8 | -1 | 1 | 1 | 1 | -1 | 37267308.55 |
| 9 | 1 | -1 | -1 | -1 | -1 | 37628674.12 |
| 10 | 1 | -1 | -1 | 1 | 1 | 37784548.32 |
| 11 | 1 | -1 | 1 | -1 | 1 | 37810789.20 |
| 12 | 1 | -1 | 1 | 1 | -1 | 37706131.66 |
| 13 | 1 | 1 | -1 | -1 | 1 | 37851310.58 |
| 14 | 1 | 1 | -1 | 1 | -1 | 37735973.39 |
| 15 | 1 | 1 | 1 | -1 | -1 | 37763402.05 |
| 16 | 1 | 1 | 1 | 1 | 1 | 37940551.10 |

***A:Germany B:U.K. C:Spain D:Italy E:Turkey***

**Table 4.11 Metamodel 3 : Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 5 | 1.1885816E12 | 237716315657 | 1846.609 | 0.0001 |
| Error | 10 | 1287312836 | 128731283.6 | | |
| C Total | 15 | 1.1898689E12 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 11345.9809 | R-square | 0.9989 |
| Dep Mean | 37521412.8031 | Adj R-sq | 0.9984 |
| C.V. | 0.0302 | | |

**Table 4.12 Metamodel 3 : Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37521413 | 2836.4952362 | 13228.089 | 0.0001 |
| A | 1 | 256260 | 2836.4952362 | 90.344 | 0.0001 |
| B | 1 | 43758 | 2836.4952362 | 15.427 | 0.0001 |
| C | 1 | 25919 | 2836.4952362 | 9.138 | 0.0001 |
| D | 1 | 14060 | 2836.4952362 | 4.957 | 0.0006 |
| E | 1 | 76374 | 2836.4952362 | 26.926 | 0.0001 |

$$\hat{Y} = 37521413 + 256260\, Z_1 + 43758\, Z_2 + 25919\, Z_3 + 14060\, Z_4 + 76374\, Z_5$$

***A:Germany B:U.K. C:Spain D:Italy E:Turkey***

### *4.2.4 Metamodel 4*

Metamodel 4 investigates the effects of the tonnage requirement of five areas and unit cost, presented in Table 3.4 and Table 3.5, on the total cost. Five areas are represented as A, B, C, D and E respectively, where A is a $113 \times 1$ RHS vector, B is a $53 \times 1$ RHS vector, C is a $102 \times 1$ RHS vector, D is a $60 \times 1$ RHS vector and E is a $32 \times 1$ RHS vector. I present the detailed data sets of tonnage requirement in Appendix G. Finally a $8 \times 1$ unit cost vector is represented as F. I use a $2^{6-2}$ fractional factorial design for this metamodel.

**Table 4.13 Metamodel 4 : minimized-cost values for 16 treatments**

| Treatment | A | B | C | D | E | F | Y |
|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | -1 | -1 | 31031465.08 |
| 2 | -1 | -1 | -1 | 1 | 1 | 1 | 37838413.62 |
| 3 | -1 | -1 | 1 | -1 | 1 | 1 | 39255219.12 |
| 4 | -1 | -1 | 1 | 1 | -1 | -1 | 33019081.82 |
| 5 | -1 | 1 | -1 | -1 | 1 | -1 | 31289031.85 |
| 6 | -1 | 1 | -1 | 1 | -1 | 1 | 37747428.12 |
| 7 | -1 | 1 | 1 | -1 | -1 | 1 | 39180415.24 |
| 8 | -1 | 1 | 1 | 1 | 1 | -1 | 33317133.39 |
| 9 | 1 | -1 | -1 | -1 | -1 | 1 | 43019902.53 |
| 10 | 1 | -1 | -1 | 1 | 1 | -1 | 36352335.10 |
| 11 | 1 | -1 | 1 | -1 | 1 | -1 | 36835327.21 |
| 12 | 1 | -1 | 1 | 1 | -1 | 1 | 44317124.26 |
| 13 | 1 | 1 | -1 | -1 | 1 | 1 | 43321115.64 |
| 14 | 1 | 1 | -1 | 1 | -1 | -1 | 36287519.48 |
| 15 | 1 | 1 | 1 | -1 | -1 | -1 | 36769465.82 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 44620933.74 |

***A: Area1 B:Area2 C:Area3 D:Area4 E:Area5 F:Unit cost***

**Table 4.14 Metamodel 4 : Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 6 | 2.8672995E14 | 4.7788325E13 | 279.599 | 0.0001 |
| Error | 9 | 1.5382542E12 | 170917138620 | | |
| C Total | 15 | 2.8826821E14 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 413421.2605 | R-square | 0.9947 |
| Dep Mean | 37762619.5013 | Adj R-sq | 0.9911 |
| C.V. | 1.0948 | | |

**Table 4.15 Metamodel 4 : Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37762620 | 103355.31512 | 365.367 | 0.0001 |
| A | 1 | 2427846 | 103355.31512 | 23.490 | 0.0001 |
| B | 1 | 54011 | 103355.31512 | 0.523 | 0.6139 |
| C | 1 | 651718 | 103355.31512 | 6.306 | 0.0001 |
| D | 1 | 174877 | 103355.31512 | 1.692 | 0.1249 |
| E | 1 | 91069 | 103355.31512 | 0.881 | 0.4012 |
| F | 1 | 3399950 | 103355.31512 | 32.896 | 0.0001 |

$$\hat{Y} = 37762620 + 2427846\ Z_1 + 54011\ Z_2 + 651718\ Z_3 + 174877\ Z_4 + 91069 Z_5 + 3399950\ Z_6$$

When I look at the Table 4.14, I observe that $R^2$ is almost one showing that I also have a good first order fit to the data. The regression polynomial in Table 4.15 shows that in case of a possible 10% change in tonnage requirement and unit cost, unit cost has the greatest effect on the total flying cost by 9.07%. When I consider five areas for the tonnage requirement, Area 1 and Area 3 are the dominating factors for the total flying cost. Among the areas, Area 1 has the greatest effect on the total flying cost by 6.47%.

### *4.2.5 Metamodel 5*

Metamodel 5 examines the effects of the frequency requirement of five areas and unit cost on the total flying cost. Five areas are represented as A, B, C, D and E, respectively, where A is a $32 \times 1$ RHS vector, B is a $48 \times 1$ RHS vector, C is a $38 \times 1$ RHS vector, D is a $24 \times 1$ RHS vector and E is a $9 \times 1$ RHS vector. I present the detailed data sets of frequency requirement in Appendix G. Finally a $8 \times 1$ unit cost vector is represented as F. I use a $2^{6-2}$ fractional factorial design for this metamodel.

**Table 4.16 Metamodel 5 : minimized-cost values for 16 treatments**

| Treatment | A | B | C | D | E | F | Y |
|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | -1 | -1 | 33740941.86 |
| 2 | -1 | -1 | -1 | 1 | 1 | 1 | 40721164.02 |
| 3 | -1 | -1 | 1 | -1 | 1 | 1 | 40952663.59 |
| 4 | -1 | -1 | 1 | 1 | -1 | -1 | 34361794.25 |
| 5 | -1 | 1 | -1 | -1 | 1 | -1 | 33907391.03 |
| 6 | -1 | 1 | -1 | 1 | -1 | 1 | 40699641.18 |
| 7 | -1 | 1 | 1 | -1 | -1 | 1 | 41018783.10 |
| 8 | -1 | 1 | 1 | 1 | 1 | -1 | 34488258.96 |
| 9 | 1 | -1 | -1 | -1 | -1 | 1 | 40809955.03 |
| 10 | 1 | -1 | -1 | 1 | 1 | -1 | 34263308.40 |
| 11 | 1 | -1 | 1 | -1 | 1 | -1 | 34340147.41 |
| 12 | 1 | -1 | 1 | 1 | -1 | 1 | 41279150.52 |
| 13 | 1 | 1 | -1 | -1 | 1 | 1 | 40953216.66 |
| 14 | 1 | 1 | -1 | 1 | -1 | -1 | 34292686.67 |
| 15 | 1 | 1 | 1 | -1 | -1 | -1 | 34328963.93 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 41374624.30 |

*A: Area1 B:Area2 C:Area3 D:Area4 E:Area5 F:Unit cost*

**Table 4.17 Metamodel 5 : Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 6 | 1.8365881E14 | 3.0609802E13 | 6076.946 | 0.0001 |
| Error | 9 | 45333335022 | 5037037224.6 | | |
| C Total | 15 | 1.8370415E14 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 70972.0876 | R-square | 0.9998 |
| Dep Mean | 37595793.1819 | Adj R-sq | 0.9996 |
| C.V. | 0.1888 | | |

**Table 4.18 Metamodel 5 : Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37595793 | 17743.021911 | 2118.906 | 0.0001 |
| A | 1 | 109463 | 17743.021911 | 6.169 | 0.0002 |
| B | 1 | 37153 | 17743.021911 | 2.094 | 0.0658 |
| C | 1 | 172255 | 17743.021911 | 9.708 | 0.0001 |
| D | 1 | 89285 | 17743.021911 | 5.032 | 0.0007 |
| E | 1 | 29304 | 17743.021911 | 1.652 | 0.1330 |
| F | 1 | 3380357 | 17743.021911 | 190.518 | 0.0001 |

$$\hat{Y} = 37595793 + 109463\,Z_1 + 37153\,Z_2 + 172255\,Z_3 + 89285\,Z_4 + 29304\,Z_5 + 3380357\,Z_6$$

In Table 4.15, I can see that $R^2$ is almost one showing that I also have a good first order fit to the data. The regression polynomial in Table 4.18 shows that in case of a possible 10% change in frequency requirement and unit cost, unit cost has the greatest effect on the total flying cost by 9.02%. When I consider five areas for the frequency requirement, Area 1, Area 3 and Area 4 are the dominating factors for the total flying cost. Especially, Area 3 has the greatest effect on the total flying cost by 0.46%.

### *4.2.6 Metamodel 6*

Metamodel 6 is the combination of Metamodel 4 and Metamodel 5. I consider 10 regional factors and 1 unit cost factor, so a total of 11 factors are used. The A to E factors are regional factors, Area 1 to Area 5, for tonnage requirement and the F to K factors are regional factors, Area 1 to Area 5, for frequency requirement, respectively. Finally, L is the unit cost factor.

In Table 4.21, the regression shows that in case of a possible 10% change in tonnage requirement, frequency requirement and unit cost, unit cost still has the greatest effect on the total flying cost by 9.11%.

**Table 4.19 Metamodel 6 : minimized-cost values for 16 treatments**

| Treatment | A | B | C | D | E | F | G | H | J | K | L | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 30614923.85 |
| 2 | -1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 37999615.25 |
| 3 | -1 | -1 | -1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 | 31840825.65 |
| 4 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 37497062.60 |
| 5 | -1 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | 39255403.02 |
| 6 | -1 | -1 | 1 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 33109325.48 |
| 7 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 39969601.23 |
| 8 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | 33264428.40 |
| 9 | -1 | 1 | -1 | -1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 31453792.93 |
| 10 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | 37361623.70 |
| 11 | -1 | 1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 1 | -1 | 31428989.56 |
| 12 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | -1 | 1 | 38206734.72 |
| 13 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 39367762.38 |
| 14 | -1 | 1 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | -1 | 33105773.39 |
| 15 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 39832511.57 |
| 16 | -1 | 1 | 1 | 1 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | 33587277.44 |
| 17 | 1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 43201581.37 |
| 18 | 1 | -1 | -1 | -1 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | 36295155.45 |
| 19 | 1 | -1 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 43539235.14 |
| 20 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 | 1 | -1 | 36471761.56 |
| 21 | 1 | -1 | 1 | -1 | -1 | -1 | 1 | -1 | 1 | 1 | -1 | 36656240.25 |
| 22 | 1 | -1 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | -1 | 1 | 44327578.18 |
| 23 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 37193754.41 |
| 24 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | 44332734.60 |
| 25 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 43556527.82 |
| 26 | 1 | 1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | 36122448.31 |
| 27 | 1 | 1 | -1 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | 43559778.04 |
| 28 | 1 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 36667327.01 |
| 29 | 1 | 1 | 1 | -1 | -1 | 1 | 1 | 1 | 1 | -1 | -1 | 37179724.73 |
| 30 | 1 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 44008280.55 |
| 31 | 1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 36751744.50 |
| 32 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 45077447.65 |

**Table 4.20 Metamodel 6 : Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | 11 | 5.7618214E14 | 11 5.2380195E13 | 246.178 | 0.0001 |
| Error | 20 | 4.2554727E12 | 212773636539 | | |
| C Total | 31 | 5.8043762E14 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 461273.9279 | R-square | 0.9927 |
| Dep Mean | 37901155.3356 | Adj R-sq | 0.9886 |
| C.V. | 1.2170 | | |

When I consider five areas for the tonnage requirement, Area 1 (effect by 6.4%) and Area 3 (effect by 1.76%) are the dominating factors for the total flying cost. When I consider five areas for the frequency requirement, Area 1, Area 3 and Area 4 are the dominating factors for the total flying cost. Especially, Area 3 has the greatest effect on the total flying cost by 0.49%.

The results of Metamodel 6 show that each factor's effect for the total flying cost is almost same when compared with Metamodel 4 and Metamodel 5.

**Table 4.21 Metamodel 6 : Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | 1 | 37901155 | 81542.480597 | 464.803 | 0.0001 |
| A | 1 | 2407677 | 81542.480597 | 29.527 | 0.0001 |
| B | 1 | 53079 | 81542.480597 | 0.651 | 0.5225 |
| C | 1 | 662569 | 81542.480597 | 8.125 | 0.0001 |
| D | 1 | 175171 | 81542.480597 | 2.148 | 0.0441 |
| E | 1 | 63506 | 81542.480597 | 0.779 | 0.4452 |
| F | 1 | 104667 | 81542.480597 | 1.284 | 0.2140 |
| G | 1 | 28138 | 81542.480597 | 0.345 | 0.7336 |
| H | 1 | 184575 | 81542.480597 | 2.264 | 0.0349 |
| J | 1 | 85820 | 81542.480597 | 1.052 | 0.3051 |
| K | 1 | 43623 | 81542.480597 | 0.535 | 0.5986 |
| L | 1 | 3417187 | 81542.480597 | 41.907 | 0.0001 |

$$\hat{Y} = 37901155 + 2407677\,Z_1 + 53079\,Z_2 + 662569\,Z_3 + 175171\,Z_4 + 63506\,Z_5 + 104667\,Z_6 + 28138\,Z_7 + 184575\,Z_8 + 85820\,Z_9 + 43623\,Z_{10} + 3417187\,Z_{11}$$

***TREQ ( A: Area1 B:Area2 C:Area3 D:Area4 E:Area5 )***

***FREQ (F: Area1 G:Area2 H:Area3 J:Area4 K:Area5 ) L:Unit cost***

### *4.3 Validation for metamodels*

In Table 4.6, I presented the comparison with validation design for Metamodel 1. By the same manner, I compared the rest of the metamodels and I show the results in Table 4.22. The predictions obtained with each of the metamodels were remarkably accurate.

**Table 4.22 Comparison with validation design for metamodels**

| Metamodel | Design | MSE | MAPE |
|---|---|---|---|
| 1 | $2^2$ Factorial Design | 3517E6 | 0.153 |
| 2 | $2^3$ Factorial Design | 9460E6 | 0.151 |
| 3 | $2_V^{5-1}$ Fractional Factorial Design | 592E6 | 0.059 |
| 4 | $2_{IV}^{6-2}$ Fractional Factorial Design | 65254E6 | 0.602 |
| 5 | $2_{IV}^{6-2}$ Fractional Factorial Design | 3701E6 | 0.137 |
| 6 | $2_{IV}^{11-6}$ Fractional Factorial Design | 115909E6 | 0.830 |

I present the detailed results of the validation for metamodels in Appendix E.

# *V. CONCLUSIONS AND RECOMMENDATIONS*

## *5.1 Conclusions*

The "Hot Start" method was very helpful for this research because I could save time and effort on the computer experiments. I used FORTRAN for the converter programs to support the "Hot Start" method and I created the "Hot Start" files by that program's successive use. The "Hot Start" method gave me good efficiency for reducing running time of large scale linear programming model.

The metamodelling methodology developed by Johnson, Bauer, Moore, and Grant for the optimality analysis of LPs works very well for the large scale linear programming models. In Chapter 4, the metamodels described the key relationships between the optimal objective function value, the total flying cost, the right-hand-side vectors and unit cost vector. I changed all factors up and down 10% and the optimal objective function value changed around 30 to 45 million dollars

The response surface of the optimal objective function value is a relatively flat surface. For that reason, the optimal objective function value can be estimated by a simple polynomial with remarkable accuracy which is shown in Chapter 4.

## *5.2 Recommendations for further study*

I used the program Excel to change the level of the RHS and unit cost vectors because the length of the data set was not too long. But if one wanted to treat a very large data set, they may use special software to make the data manipulations in less time.

This thesis effort limited itself by changing the RHS (tonnage and frequency requirement) and unit cost vectors of STORM by 10%. One may study perturbing the vectors of interest for various levels of change and attaching another RHS vectors. I also recommend additional research for traversing the experimental design efficiently.

# Appendix A. The modified STORM and FORTRAN convertor program for "Hot Start" method

## *1. The modified STORM model for "Hot Start"*

```
* GAMS FORMULATION OF STORM MODEL

* HOT START TECHNIQUE FOR STORM

$OFFSYMXREF OFFSYMLIST
OPTIONS SOLPRINT=OFF, LIMCOL=0, LIMROW=0, SYSOUT=OFF ;

SETS
 aircraft PLANE TYPES /
$INCLUDE "planes.stm"
 /
 stp NUMBERED SEQUENCE OF STOPS IN ROUTE /01 * 15/ ;
ALIAS (stp,st2);
SET routes AIRCRAFT ROUTES /
$INCLUDE "route.tmp"
 / ;

SET c CITIES /
$INCLUDE "bases.stm"
  / ;
ALIAS (c,cd,ct) ;
SETS tp(ct,cd) TRANSSHIPMENT BALANCE PAIRS /
$INCLUDE "trans.tmp"
  /
   dvar(routes,stp,st2) COMBINATIONS FOR DIRECT DELIVERY /
$INCLUDE "d.var"
  /
   svar(routes,stp,st2) SECOND HALF OF TRANSSHIPMENT DELIVERY /
$INCLUDE "s.var"
  /
   tvar(routes,stp,st2,cd) FIRST HALF OF TRANSSHIPMENT DELIVERY /
$INCLUDE "t.var"
  /
   onrte(routes,stp,st2,c,ct) EACH ROUTES SEQUENCE OF STOPS /
$INCLUDE "onroute.tmp"
  /
   start(routes,c) STARTING CITY OF EACH ROUTE /
$INCLUDE "start.tmp"
  /
   ends(routes,c) ENDING CITY OF EACH ROUTE /
$INCLUDE "ends.tmp"
```

```
 / ;

PARAMETERS LENGTH(routes) NUMBER OF CITIES VISITED BY ROUTE /
$INCLUDE "lengths.tmp"
 /
      V(routes,c) NUMBER OF VISITS TO EACH CITY BY EACH ROUTE /
$INCLUDE "visits.tmp"
 /
      TC(c,cd) TOTAL CARGO TO BE MOVED BETWEEN CITIES /
$INCLUDE "load.tmp"
 /
      CF(c,cd) FREQUENCY REQS BETWEEN CITIES /
$INCLUDE "freq.tmp"
 / ;

TABLE H(routes,aircraft) FLYING HOUR ARRAY
$INCLUDE "times.stm"
   ;

PARAMETER ML(c) MAXIMUM NUMBER OF MISSIONS TO EACH CITY ;
ML(c) = 1000 ;

TABLE AC(aircraft,*) AIRCRAFT INFORMATION
$INCLUDE "misc.stm"
   ;

SCALAR B  CARGO HANDLING COST PER TON /176.0/ ;
SCALARS CARGUNM, CARGTOT ;
FREE VARIABLES Z ;
POSITIVE VARIABLES
   Y(c,cd) UNDELIVERED CARGO
   X(routes,aircraft) SORTIES ON A ROUTE BY AN AIRCRAFT TYPE
   D(routes,stp,st2) DIRECT DELIVERY CARGO
   T(routes,stp,st2,cd) FIRST PART OF TRANSSHIPMENT DELIVERY
   S(routes,stp,st2) SECOND PART OF TRANSSHIPMENT DELIVERY
   SLK(routes,stp) UNUSED CAPACITY ON EACH LEG OF EACH ROUTE ;

*** BOUNDS ON 'X' VARIABLES INCLUDED IN FILE 'LXODA.STM'.
$INCLUDE "lx.stm"


$INCLUDE "YL.STM"
$INCLUDE "XL.STM"
$INCLUDE "DL.STM"
$INCLUDE "SL.STM"
```

```
$INCLUDE "TL.STM"
$INCLUDE "SLKL.STM"

EQUATIONS
 TREQ(c,cd) tonnage required to move between city pairs
 CARGB(ct,cd) cargo transshipped in equals cargo transhipped out
 PL1(routes) capacity constraint on first leg of a route
 PLP(routes,stp) capacity constraint on other legs of route
 ABAL(c,aircraft) landings equals takeoffs for each plane type
 FREQ(c,cd) meet frequency requirements
 UPHRS(aircraft) upper limit on aircraft flying hours
 LOHRS(aircraft) lower limit on aircraft flying hours
 MAXLND(c) maximum number of landings at any base
 COSTS objective function of flying and handling costs ;

TREQ(c,cd)$TC(c,cd).. TC(c,cd) =L= Y(c,cd) +
  SUM((routes,stp,st2)$(dvar(routes,stp,st2)$onrte(routes,stp,st2,c,cd)),
     D(routes,stp,st2)) +
  SUM((routes,stp,st2,ct)$(tvar(routes,stp,st2,cd)$onrte(routes,stp,st2,c,ct)),
     T(routes,stp,st2,cd)) ;

CARGB(ct,cd) $tp(ct,cd)..
  SUM((routes,stp,st2,c) $(tvar(routes,stp,st2,cd)$onrte(routes,stp,st2,c,ct)),
     T(routes,stp,st2,cd)) =E=
  SUM((routes,stp,st2) $(svar(routes,stp,st2)$onrte(routes,stp,st2,ct,cd)),
     S(routes,stp,st2)) ;

PL1(routes).. SUM(aircraft $H(routes,aircraft),
     AC(aircraft,"PAY") * X(routes,aircraft)) =E= SLK(routes,"01") +
  SUM(st2 $dvar(routes,"01",st2), D(routes,"01",st2)) +
  SUM(st2 $svar(routes,"01",st2), S(routes,"01",st2)) +
  SUM((st2,cd) $tvar(routes,"01",st2,cd), T(routes,"01",st2,cd)) ;

PLP(routes,stp)$(ORD(stp) lt LENGTH(routes) and ORD(stp) ge 2)..
       SLK(routes,stp-1) +
  SUM(st2 $dvar(routes,st2,stp), D(routes,st2,stp)) +
  SUM(st2 $svar(routes,st2,stp), S(routes,st2,stp)) +
  SUM((st2,cd) $tvar(routes,st2,stp,cd), T(routes,st2,stp,cd))

    =E= SLK(routes,stp) +
  SUM(st2 $dvar(routes,stp,st2), D(routes,stp,st2)) +
  SUM(st2 $svar(routes,stp,st2), S(routes,stp,st2)) +
  SUM((st2,cd) $tvar(routes,stp,st2,cd), T(routes,stp,st2,cd)) ;

ABAL(c,aircraft)..
```

```
  SUM(routes$(start(routes,c) $H(routes,aircraft)),X(routes,aircraft))
                    =E=
  SUM(routes$(ends(routes,c) $H(routes,aircraft)),X(routes,aircraft)) ;

FREQ(c,cd) $CF(c,cd).. CF(c,cd) =L=
  SUM((routes,aircraft)$H(routes,aircraft),
     SUM((stp,st2)$onrte(routes,stp,st2,c,cd),
       X(routes,aircraft))) ;

UPHRS(aircraft).. SUM(routes $H(routes,aircraft),
    H(routes,aircraft) * X(routes,aircraft))
     =L= AC(aircraft,"FH") ;

LOHRS(aircraft).. SUM(routes $H(routes,aircraft),
    H(routes,aircraft) * X(routes,aircraft))
     =G= AC(aircraft,"LH") ;

MAXLND(c)$(ML(c) le 999).. ML(c) =G= SUM((routes,aircraft)
   $H(routes,aircraft), V(routes,c) * X(routes,aircraft)) ;

COSTS.. Z =E= SUM((routes,aircraft) $H(routes,aircraft),
     AC(aircraft,"COST") * H(routes,aircraft) * X(routes,aircraft))
  + SUM((routes,aircraft) $(start(routes,"EXXX") $H(routes,aircraft)),
   0.8 * AC(aircraft,"COST") * H(routes,aircraft) * X(routes,aircraft))
   + B * SUM((routes,stp,st2)$dvar(routes,stp,st2),D(routes,stp,st2))
   + 2 * B * SUM((routes,stp,st2)$svar(routes,stp,st2),S(routes,stp,st2))
   + 10000 * SUM((c,cd)$TC(c,cd),Y(c,cd)) ;


MODEL STORM1 /ALL/ ;

OPTION ITERLIM = 40000 ;
OPTION LP = XA ;
SOLVE STORM1 USING LP MINIMIZING Z ;
DISPLAY Z.L ;

file res1 /newyl.txt/ ;
put res1 ;
loop ((c,cd), put c.TL:7, cd.TL:7, Y.L(c,cd):4:2 / ;
    );

file res2 /newxl.txt/ ;
put res2 ;
loop ((routes,aircraft), put routes.TL:7,aircraft.TL:7,
     X.L(routes,aircraft): 6:3/ ;);
```

```
files res3 /newdl.txt/ ;
put res3 ;
loop ((routes,stp,st2), put routes.TL:7, stp.TL:7,
    st2.TL:7, D.L(routes,stp,st2):7:3/;) ;

files res4 /newtl.txt/ ;
put res4 ;
loop ((routes,stp,st2,cd), put routes.TL:7, stp.TL:7,
    st2.TL:7, T.L(routes,stp,st2,cd):7:3/;) ;

files res5 /newsl.txt/ ;
put res5 ;
loop ((routes,stp,st2), put routes.TL:7, stp.TL:7,
    st2.TL:7, S.L(routes,stp,st2):7:3/;) ;


files res6 /newslk.txt/ ;
put res6 ;
loop ((routes,stp), put routes.TL:7, stp.TL:7,
    SLK.L(routes,stp):7:3/;) ;
```

I modified the original STORM model. The bold lines are attached program for "Hot Start" method.

## *2. FORTRAN convertor program for "Hot Start"*

```
c THIS IS THE CONVERTOR PROGRAM FOR "XL.STM"


      character*4  c1,c2,zero
      real         c3
      parameter(zero='    ')


      open (1,file='newxl.txt ',status='old')
      open (2,file= 'xl.stm',status='unknown')


 400    read(1,10,end=99 ) c1,c2,c3
  10    format (a4, 3x, a4, 3x, f6.3 )
```

```
      if( c1.eq.zero)      go to 15
      if(c2.eq.zero)       go to 15
      if(c3.eq.0.000 )     go to 15

      write(2,20) c1,c2,c3

 15 go to 400

 20     format(1x,'X.L("',a4,'","',a4,'") = ', f6.3,' ;')


 99 close(1)
    close(2)
    stop
    end
```

---

**c THIS IS THE CONVERTER PROGRAM FOR "YL.STM"**

```
    character*4   c1,c2
    real c3
    character*4   zero,zero1
    parameter(zero='    ')
    parameter(zero1='0.00')

    open (unit=1,file='newyl.txt',status='old')
    open (unit=2,file= 'yl.stm',status='unknown')

 100      read(1,10, end=99) c1, c2, c3
  10      format (a4,3x,a4,3x, f4.2 )

      if(c1.eq.zero)     go to 15
      if(c2.eq.zero)     go to 15
      if(c3.eq.0.00 )    go to 15

      write(2,20) c1,c2,c3
 15 go to 100
 20     format(1x,'Y.L("',a4,'","',a4,'") = ', f4.2,' ;')

 99 close (unit=1)
    close (unit=2)
```

```
    stop
    end
```
---

**c THIS IS THE CONVERTER PROGRAM "DL.STM"**

```
    character*4   c1
    character*2   c2, c3
    real          c4


    open (1,file='newdl.txt',status='old')
    open (2,file='dl.stm',status='unknown')


 400 read (1,10,end=99)  c1, c2, c3, c4
  10 format (a4, 3x, a2, 5x, a2 , 5x, f7.3 )



       if( c4.eq.0.000 )    go to 15

       write(2,20) c1,c2,c3,c4
  15 go to 400

  20     format(1x,'D.L(''',a4,''',''',a2,''',''',a2,''') = ',f7.3 ,' ;')

   99 close(1)
     close(2)
     stop
     end
```
---

The convertor program for “SL.STM”, “TL.STM”, “SLKL.STM” are almost same with the program for DL.STM

# Appendix B. “Hot Start” files for STORM

Y(c,cd): The number of tons of cargo from source base 'c' which cannot be delivered to final destination bases 'cd' and "YL.STM" file contains the prime values for each of Y(c,cd) variables.

This is output file "YL.STM"

```
Y.L("KDOV","RODN") = 8.87 ;
Y.L("KSUU","OBBI") = 0.04 ;
Y.L("KSUU","OEDR") = 0.02 ;
Y.L("RJTY","EDAF") = 0.28 ;
```

X(routes, aircraft): The number of missions to be flown on a route by aircraft type and "XL.STM" file contains the prime values for each of X(routes, aircraft) variables.

This is output file "XL.STM"

```
X.L("0001","C141") = 12.000 ;
X.L("0001","B747") =  6.403 ;
X.L("0007","C005") =  0.084 ;
X.L("0012","B747") = 10.722 ;
X.L("0016","C005") =  1.676 ;
X.L("0018","C141") =  6.087 ;
X.L("0021","B747") =  2.423 ;
X.L("0022","C141") =  4.487 ;
X.L("0024","C005") =  0.238 ;
X.L("0027","C141") =  0.986 ;
      .       .       .
      .       .       .
      .       .       .
X.L("0227","C141") =  2.000 ;
X.L("0230","C141") =  0.387 ;
X.L("0231","C141") =  0.206 ;
X.L("0232","C141") =  1.162 ;
```

D(routes, stp, st2): The number of tons of cargo to be delivered directly from stop number 'stp' of the route (its origin) to stop number 'st2' of the route (its destination) and "DL.STM" file contains the prime values for each of D(routes, stp, st2) variables.

This is output file "DL.STM"

```
D.L("0001","01","02") = 661.511 ;
D.L("0001","02","03") = 573.181 ;
D.L("0007","01","02") =   3.020 ;
D.L("0007","01","03") =   1.170 ;
D.L("0007","02","04") =   3.020 ;
D.L("0007","03","04") =   1.170 ;
D.L("0007","04","06") =   4.190 ;
        .        .          .
        .        .          .
        .        .          .
D.L("0223","02","03") =   2.310 ;
D.L("0227","01","04") =  36.000 ;
D.L("0227","04","05") =  36.000 ;
D.L("0230","01","02") =   1.310 ;
D.L("0230","01","03") =   5.650 ;
D.L("0231","01","05") =   3.700 ;
D.L("0232","02","03") =  11.010 ;
D.L("0232","03","05") =  10.280 ;
D.L("0232","04","05") =  10.630 ;
```

S(routes, stp, st2): The number of tons picked up at a transshipment point (stop number 'stp' of the route) and delivered to its final destination (stop number 'st2') and "SL.STM" file contains the prime values for each of S(routes, stp, st2) variables.

This is output file "SL.STM"

```
S.L("0001","02","03") =  97.400 ;
S.L("0012","03","05") = 260.537 ;
S.L("0027","06","07") =  17.744 ;
S.L("0033","05","07") =   9.524 ;
S.L("0063","02","03") =   5.740 ;
S.L("0072","03","04") =   0.190 ;
S.L("0079","01","03") =   1.920 ;
S.L("0095","01","04") =  26.230 ;
       .          .            .
       .          .            .
       .          .            .
S.L("0219","01","02") =  64.340 ;
S.L("0220","01","03") =   9.310 ;
S.L("0221","01","02") =  24.880 ;
S.L("0222","01","03") =  17.360 ;
S.L("0223","01","02") =  18.680 ;
S.L("0230","02","03") =   1.310 ;
S.L("0230","04","05") =   6.960 ;
S.L("0232","02","03") =   9.900 ;
```

T(routes, stp, st2, cd): The number of tons picked up at its origin ('stp') and dropped off at a transshipment point ('st2') for eventual delivery to its final destination base 'cd' and "TL.STM" file contains the prime values for each of T(routes, stp, st2, cd) variables.

This is output file "TL.STM"

```
T.L("0001","01","02","LGIR") =   9.070 ;
T.L("0012","01","03","FJDG") =  40.330 ;
T.L("0012","01","03","VTBD") =   9.090 ;
T.L("0012","01","03","WSAP") =  18.680 ;
T.L("0012","01","03","RKJK") =   4.577 ;
T.L("0012","01","03","RJOI") =   0.370 ;
T.L("0012","01","03","RODN") = 239.214 ;
T.L("0012","01","03","RJSM") = 108.690 ;
       .          .            .
       .          .            .
```

.          .          .

```
T.L("0201","11","13","OEDR") =  0.820 ;
T.L("0202","04","07","LTAG") =  5.510 ;
T.L("0202","05","07","OEDR") =  1.980 ;
T.L("0215","02","04","KCHS") =  3.670 ;
T.L("0217","02","04","KCHS") =  6.680 ;
T.L("0219","02","03","KCHS") = 12.010 ;
T.L("0220","03","04","KCHS") =  5.550 ;
T.L("0232","01","02","OERY") = 20.910 ;
```

SLK(routes, stp): The unused cargo capacity on the 'stp'th leg of the route and "SLKL.STM" file contains the prime values for each of SLK(routes, stp) variables

This is output file "SLKL.STM"

```
SLK.L("0007","06") =   4.190 ;
SLK.L("0012","03") = 145.824 ;
SLK.L("0012","04") =  57.180 ;
SLK.L("0018","05") =  90.980 ;
SLK.L("0018","06") =  61.900 ;
SLK.L("0021","03") =  88.137 ;
SLK.L("0021","04") =  82.894 ;
SLK.L("0027","03") =   5.059 ;
   .          .          .
   .          .          .
   .          .          .
SLK.L("0220","03") =   4.240 ;
SLK.L("0221","01") =   4.740 ;
SLK.L("0221","02") =  52.790 ;
SLK.L("0221","03") =  52.990 ;
SLK.L("0222","02") =   9.790 ;
SLK.L("0222","03") =  35.520 ;
SLK.L("0223","02") =  42.660 ;
SLK.L("0230","03") =   6.960 ;
SLK.L("0231","05") =   3.700 ;
SLK.L("0232","03") =  10.630 ;
```

# Appendix C. The compared result between "Hot Start" and non-"Hot Start"

< Metamodel 1 >

TREQ down 10% (-1)    FREQ down 10% (-1)

```
==========================================

GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                  G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD-10.TMP(360)
--- .FREQ-10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- STORM.GMS(162)
--- Starting execution
--- STORM.GMS(10296)
--- Generating model STORM1
--- STORM.GMS(10297)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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                        GAMS/XA Program Version 4.0 - Serial Number 501101

STATISTICS - GAMS Fri Feb 14 22:19:42 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.
```

```
Iter: 50 Inf:    689.34340 43
Iter: 100 Inf:    438.78156 29
Iter: 150 Inf:    202.19353 26
Iter: 200 Inf:     67.26518 15
Iter: 250 Inf:     37.38722 8
Iter: 300 Inf:      3.08323 1
Iter: 350 Inf:      3.08323 1
Iter: 400 Obj: 169558907.2 67
Iter: 450 Obj: 168294921.8 66
Iter: 500 Obj: 166337555.9 66
Iter: 550 Obj: 164495459.5 64
Iter: 600 Obj: 163164724.7 68
Iter: 650 Obj: 157553783.2 61
Iter: 700 Obj: 147064831.3 65
Iter: 750 Obj: 144996001.3 70
Iter: 800 Obj: 143356360.8 66
Iter: 850 Obj: 141780170.1 58
Iter: 900 Obj: 140816222.2 60
Iter: 950 Obj: 139760765.5 64
Iter: 1000 Obj: 135291910.3 61
Iter: 1050 Obj: 133510947.0 57
Iter: 1100 Obj: 131481482.1 63
Iter: 1150 Obj: 124528907.3 60
Iter: 1200 Obj: 120363107.7 57
Iter: 1250 Obj: 113290812.2 58
Iter: 1300 Obj: 97167390.30 66
Iter: 1350 Obj: 95802016.82 66
Iter: 1400 Obj: 85991230.82 68
Iter: 1450 Obj: 81650151.56 58
Iter: 1500 Obj: 76879440.68 55
Iter: 1550 Obj: 75624650.49 61
Iter: 1600 Obj: 71628969.45 60
Iter: 1650 Obj: 69479928.51 64
Iter: 1700 Obj: 64678271.41 62
Iter: 1750 Obj: 61316675.74 52
Iter: 1800 Obj: 58627728.71 56
Iter: 1850 Obj: 56075850.35 58
Iter: 1900 Obj: 52657935.63 60
Iter: 1950 Obj: 49625926.27 56
Iter: 2000 Obj: 47945361.09 60
Iter: 2050 Obj: 46475319.36 55
Iter: 2100 Obj: 45333513.52 60
Iter: 2150 Obj: 45056856.56 58
Iter: 2200 Obj: 44568088.49 67
Iter: 2250 Obj: 44077234.49 56
Iter: 2300 Obj: 43517833.94 62
Iter: 2350 Obj: 43405369.36 56
Iter: 2400 Obj: 43182630.84 56
Iter: 2450 Obj: 42885500.17 64
Iter: 2500 Obj: 42549668.46 58
Iter: 2550 Obj: 41841238.39 53
Iter: 2600 Obj: 41448016.43 60
Iter: 2650 Obj: 41158609.13 53
Iter: 2700 Obj: 40781302.45 59
Iter: 2750 Obj: 40245710.82 58
Iter: 2800 Obj: 40017430.55 57
Iter: 2850 Obj: 39542814.90 60
Iter: 2900 Obj: 39097527.48 57
```

```
Iter: 2950 Obj: 38994817.52 53
Iter: 3000 Obj: 38629410.72 56
Iter: 3050 Obj: 38590743.37 58
Iter: 3100 Obj: 38463861.86 53
Iter: 3150 Obj: 38250420.79 60
Iter: 3200 Obj: 38107152.84 56
Iter: 3250 Obj: 38080791.31 56
Iter: 3300 Obj: 37868743.05 54
Iter: 3350 Obj: 37759353.19 56
Iter: 3400 Obj: 37633524.27 56
Iter: 3450 Obj: 37593861.48 54
Iter: 3500 Obj: 37445343.84 53
Iter: 3550 Obj: 37310904.70 52
Iter: 3600 Obj: 37172004.28 56
Iter: 3650 Obj: 37029828.68 60
Iter: 3700 Obj: 36887733.75 60
Iter: 3750 Obj: 36620594.62 51
Iter: 3800 Obj: 36593443.67 56
Iter: 3850 Obj: 36427906.59 53
Iter: 3900 Obj: 36408130.85 54
Iter: 3950 Obj: 36340289.40 54
Iter: 4000 Obj: 36305134.10 54
Iter: 4050 Obj: 36187442.57 57
Iter: 4100 Obj: 35798891.12 56
Iter: 4150 Obj: 35675243.34 51
Iter: 4200 Obj: 35656506.36 54
Iter: 4250 Obj: 35611259.82 55
Iter: 4300 Obj: 35513341.92 53
Iter: 4350 Obj: 35471160.28 57
Iter: 4400 Obj: 35344091.83 59
Iter: 4450 Obj: 35231359.39 56
Iter: 4500 Obj: 35211420.70 56
Iter: 4550 Obj: 35193939.14 63
Iter: 4600 Obj: 35057117.83 58
Iter: 4650 Obj: 35026360.15 51
Iter: 4700 Obj: 35012632.26 55
Iter: 4750 Obj: 34966915.71 55
Iter: 4800 Obj: 34962396.99 50
Iter: 4850 Obj: 34949578.06 60
Iter: 4900 Obj: 34916119.86 55
Iter: 4950 Obj: 34813873.75 54
Iter: 5000 Obj: 34742964.19 56
Iter: 5050 Obj: 34691005.90 50
Iter: 5100 Obj: 34622126.21 55
Iter: 5150 Obj: 34378786.91 55
Iter: 5200 Obj: 34350415.32 53
Iter: 5250 Obj: 34333843.49 59
Iter: 5300 Obj: 34319415.74 58
Iter: 5350 Obj: 34289391.13 53
Iter: 5400 Obj: 34274754.18 55
Iter: 5450 Obj: 34249958.70 50
Iter: 5500 Obj: 34236125.59 52
Iter: 5550 Obj: 34222759.86 54
Iter: 5600 Obj: 34209027.58 54
Iter: 5650 Obj: 34177245.96 56
Iter: 5700 Obj: 34158801.28 53
Iter: 5750 Obj: 34152731.41 53
Iter: 5800 Obj: 34135239.35 53
Iter: 5850 Obj: 34123228.02 52
Iter: 5900 Obj: 34116161.67 53
```

```
Iter: 5950 Obj: 34100145.78 52
Iter: 6000 Obj: 34075523.43 51
Iter: 6050 Obj: 34064824.19 51
Iter: 6100 Obj: 34051647.46 50
Iter: 6150 Obj: 34047631.87 53
Iter: 6200 Obj: 34027808.58 51
Iter: 6250 Obj: 34003359.21 53
Iter: 6300 Obj: 33981009.54 50
Iter: 6350 Obj: 33908543.67 51
Iter: 6400 Obj: 33897210.70 56
Iter: 6450 Obj: 33887407.37 54
Iter: 6500 Obj: 33884757.66 51
Iter: 6550 Obj: 33876804.46 54
Iter: 6600 Obj: 33859456.75 52
Iter: 6650 Obj: 33857372.02 50
Iter: 6700 Obj: 33853179.97 51
Iter: 6750 Obj: 33848412.17 51
Iter: 6800 Obj: 33828936.96 50
Iter: 6850 Obj: 33818896.64 50
Iter: 6900 Obj: 33788475.81 50
Iter: 6950 Obj: 33770874.90 51
Iter: 7000 Obj: 33758417.41 50
Iter: 7050 Obj: 33747382.02 50
Iter: 7100 Obj: 33736880.98 51
Iter: 7150 Obj: 33719007.06 50
Iter: 7200 Obj: 33711903.00 50
Iter: 7250 Obj: 33704562.67 52
Iter: 7300 Obj: 33701471.13 50
Iter: 7350 Obj: 33654803.90 50
Iter: 7400 Obj: 33654309.22 34
Iter: 7450 Obj: 33653034.30 34
Iter: 7500 Obj: 33651217.52 29
Iter: 7550 Obj: 33648481.86 32
Iter: 7600 Obj: 33647635.88 26
Iter: 7650 Obj: 33646591.93 15
Iter: 7700 Obj: 33644892.66 2

O P T I M A L   S O L U T I O N ---> OBJECTIVE 33644710.27
SOLVE TIME 00:00:32   ITER 7,748  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(10297)
--- Reading solution for model STORM1
--- STORM.GMS(10298)
--- All done
```

< Metamodel 1 >

(Hot start)

TREQ down 10% (-1)    FREQ down 10% (-1)

```
GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                  G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD-10.TMP(360)
--- .FREQ-10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- .YL.STM(4)
--- .XL.STM(135)
--- .DL.STM(395)
--- .TL.STM(82)
--- .D2L.STM(44)
--- .SL.STM(67)
--- .SLKL.STM(207)
--- .SLK2L.STM(30)
--- STORM.GMS(181)
--- Starting execution
--- STORM.GMS(11279)
--- Generating model STORM1
--- STORM.GMS(11280)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   San Marino, California  91108   U.S.A.
   All Rights Reserved Worldwide.
   Telephone 818-441-1565   FAX 818-441-1567

                        GAMS/XA Program Version 4.0 - Serial Number 501101
```

```
STATISTICS - GAMS Fri Feb 14 23:33:56 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.


Iter: 50 Inf:    697.62601 49
Iter: 100 Inf:    530.00098 30
Iter: 150 Inf:    180.39553 20
Iter: 200 Inf:     49.30065 11
Iter: 250 Inf:      3.08323 1
Iter: 300 Inf:      3.08323 1
Iter: 350 Obj: 172148837.0 69
Iter: 400 Obj: 166738608.8 63
Iter: 450 Obj: 156284588.4 69
Iter: 500 Obj: 155823324.2 66
Iter: 550 Obj: 151057146.8 60
Iter: 600 Obj: 145634545.1 56
Iter: 650 Obj: 141672793.2 66
Iter: 700 Obj: 140983399.5 68
Iter: 750 Obj: 137945011.9 59
Iter: 800 Obj: 134895542.1 66
Iter: 850 Obj: 132415490.7 61
Iter: 900 Obj: 128387449.9 61
Iter: 950 Obj: 124283472.9 65
Iter: 1000 Obj: 119780087.1 57
Iter: 1050 Obj: 116250625.7 67
Iter: 1100 Obj: 115251385.0 66
Iter: 1150 Obj: 100575223.2 66
Iter: 1200 Obj: 95553610.51 57
Iter: 1250 Obj: 89173438.06 61
Iter: 1300 Obj: 82833676.53 56
Iter: 1350 Obj: 73591349.16 50
Iter: 1400 Obj: 69319315.83 60
Iter: 1450 Obj: 67612244.73 53
Iter: 1500 Obj: 57183396.25 53
Iter: 1550 Obj: 54816837.74 64
Iter: 1600 Obj: 53699178.27 59
Iter: 1650 Obj: 52175161.29 54
Iter: 1700 Obj: 51809667.55 54
Iter: 1750 Obj: 50498867.98 58
Iter: 1800 Obj: 50157274.37 57
Iter: 1850 Obj: 49518197.88 51
Iter: 1900 Obj: 48119144.47 57
Iter: 1950 Obj: 47585116.88 57
Iter: 2000 Obj: 47367954.52 58
Iter: 2050 Obj: 46975123.31 58
Iter: 2100 Obj: 46042384.92 57
Iter: 2150 Obj: 45165955.41 57
Iter: 2200 Obj: 44653925.62 56
Iter: 2250 Obj: 43999048.44 59
Iter: 2300 Obj: 43140096.31 58
Iter: 2350 Obj: 42927336.97 55
Iter: 2400 Obj: 42389904.03 56
Iter: 2450 Obj: 42313222.44 62
Iter: 2500 Obj: 42114427.88 60
```

```
Iter: 2550 Obj: 41868870.43 55
Iter: 2600 Obj: 41759957.05 57
Iter: 2650 Obj: 41352620.36 55
Iter: 2700 Obj: 40878203.99 58
Iter: 2750 Obj: 40662379.94 63
Iter: 2800 Obj: 40497523.84 65
Iter: 2850 Obj: 39744916.53 59
Iter: 2900 Obj: 39203568.98 59
Iter: 2950 Obj: 38704486.22 55
Iter: 3000 Obj: 38413402.69 58
Iter: 3050 Obj: 38316401.68 54
Iter: 3100 Obj: 38229724.34 56
Iter: 3150 Obj: 38173866.73 55
Iter: 3200 Obj: 38074812.90 56
Iter: 3250 Obj: 38004278.39 54
Iter: 3300 Obj: 37950483.32 55
Iter: 3350 Obj: 37436249.79 57
Iter: 3400 Obj: 37323570.80 55
Iter: 3450 Obj: 37232677.18 60
Iter: 3500 Obj: 37183871.70 53
Iter: 3550 Obj: 37047836.90 51
Iter: 3600 Obj: 36763627.43 61
Iter: 3650 Obj: 36655092.43 58
Iter: 3700 Obj: 36493263.11 55
Iter: 3750 Obj: 36394851.47 55
Iter: 3800 Obj: 36332159.11 53
Iter: 3850 Obj: 36256760.85 54
Iter: 3900 Obj: 36200525.60 51
Iter: 3950 Obj: 36090540.77 55
Iter: 4000 Obj: 36054541.66 54
Iter: 4050 Obj: 36007144.50 62
Iter: 4100 Obj: 35992416.40 52
Iter: 4150 Obj: 35964704.91 51
Iter: 4200 Obj: 35910906.74 50
Iter: 4250 Obj: 35714567.04 53
Iter: 4300 Obj: 35688163.74 56
Iter: 4350 Obj: 35643429.34 54
Iter: 4400 Obj: 35595018.67 56
Iter: 4450 Obj: 35532697.41 56
Iter: 4500 Obj: 35413499.22 55
Iter: 4550 Obj: 35362689.16 59
Iter: 4600 Obj: 35297618.94 53
Iter: 4650 Obj: 35172227.52 56
Iter: 4700 Obj: 35137564.06 55
Iter: 4750 Obj: 34944200.13 54
Iter: 4800 Obj: 34913216.39 55
Iter: 4850 Obj: 34891290.42 59
Iter: 4900 Obj: 34884081.37 54
Iter: 4950 Obj: 34835063.40 57
Iter: 5000 Obj: 34800007.06 50
Iter: 5050 Obj: 34744805.86 54
Iter: 5100 Obj: 34707658.92 52
Iter: 5150 Obj: 34601189.94 57
Iter: 5200 Obj: 34558849.86 52
Iter: 5250 Obj: 34545495.40 52
Iter: 5300 Obj: 34499455.22 54
Iter: 5350 Obj: 34448536.52 55
Iter: 5400 Obj: 34418578.40 57
Iter: 5450 Obj: 34372938.70 59
Iter: 5500 Obj: 34335304.42 56
```

```
Iter: 5550 Obj: 34242808.65 52
Iter: 5600 Obj: 34198168.50 52
Iter: 5650 Obj: 34114371.74 51
Iter: 5700 Obj: 34065669.39 57
Iter: 5750 Obj: 34015268.31 51
Iter: 5800 Obj: 34005534.79 54
Iter: 5850 Obj: 33885883.22 50
Iter: 5900 Obj: 33857042.32 50
Iter: 5950 Obj: 33839297.82 50
Iter: 6000 Obj: 33831090.35 52
Iter: 6050 Obj: 33818665.13 51
Iter: 6100 Obj: 33811286.29 52
Iter: 6150 Obj: 33789567.10 51
Iter: 6200 Obj: 33780205.57 51
Iter: 6250 Obj: 33761147.21 52
Iter: 6300 Obj: 33755371.61 52
Iter: 6350 Obj: 33739747.21 50
Iter: 6400 Obj: 33733000.12 50
Iter: 6450 Obj: 33722670.98 50
Iter: 6500 Obj: 33714041.46 52
Iter: 6550 Obj: 33712922.41 50
Iter: 6600 Obj: 33709682.33 44
Iter: 6650 Obj: 33706010.49 44
Iter: 6700 Obj: 33661200.99 37
Iter: 6750 Obj: 33654121.07 37
Iter: 6800 Obj: 33651396.77 19
Iter: 6850 Obj: 33650018.43 19
Iter: 6900 Obj: 33649259.22 19
Iter: 6950 Obj: 33647972.25 19
Iter: 7000 Obj: 33646607.77 15

O P T I M A L   S O L U T I O N ---> OBJECTIVE 33644710.27
SOLVE TIME 00:00:28  ITER 7,042  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(11280)
--- Reading solution for model STORM1
--- STORM.GMS(11281)
--- All done
```

< Metamodel 1 >

TREQ down 10% (-1)    FREQ up 10% (+1)

```
GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology               G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD-10.TMP(360)
--- .FREQ10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- STORM.GMS(162)
--- Starting execution
--- STORM.GMS(10296)
--- Generating model STORM1
--- STORM.GMS(10297)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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                         GAMS/XA Program Version 4.0 - Serial Number 501101

STATISTICS - GAMS Fri Feb 14 22:23:26 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.
```

```
Iter: 50 Inf:   836.56447 51
Iter: 100 Inf:   653.56886 32
Iter: 150 Inf:   350.40085 25
Iter: 200 Inf:   106.95349 19
Iter: 250 Inf:    70.90100 17
Iter: 300 Inf:    56.87299 11
Iter: 350 Inf:    15.04404 6
Iter: 400 Inf:     4.36655 2
Iter: 450 Inf:     0.00000 0
Iter: 500 Obj: 169363962.3 59
Iter: 550 Obj: 160904439.3 70
Iter: 600 Obj: 158120651.6 62
Iter: 650 Obj: 155951075.2 62
Iter: 700 Obj: 153989124.9 62
Iter: 750 Obj: 151731183.3 61
Iter: 800 Obj: 147685470.9 62
Iter: 850 Obj: 141974219.5 64
Iter: 900 Obj: 141024843.4 64
Iter: 950 Obj: 140150367.7 65
Iter: 1000 Obj: 138538221.6 64
Iter: 1050 Obj: 137048670.4 67
Iter: 1100 Obj: 133870552.7 68
Iter: 1150 Obj: 130473428.3 65
Iter: 1200 Obj: 130129320.6 62
Iter: 1250 Obj: 127607347.2 68
Iter: 1300 Obj: 123023042.1 62
Iter: 1350 Obj: 122384224.5 58
Iter: 1400 Obj: 121917195.4 61
Iter: 1450 Obj: 120184460.0 65
Iter: 1500 Obj: 113701532.1 62
Iter: 1550 Obj: 107090312.8 60
Iter: 1600 Obj: 105720051.9 58
Iter: 1650 Obj: 104102460.2 64
Iter: 1700 Obj: 101332275.8 60
Iter: 1750 Obj: 100742926.1 60
Iter: 1800 Obj: 100627589.9 58
Iter: 1850 Obj: 99997150.63 55
Iter: 1900 Obj: 94823170.49 59
Iter: 1950 Obj: 83682398.87 63
Iter: 2000 Obj: 81130245.44 59
Iter: 2050 Obj: 73029397.46 63
Iter: 2100 Obj: 68613078.57 56
Iter: 2150 Obj: 62383836.52 59
Iter: 2200 Obj: 60027060.00 57
Iter: 2250 Obj: 57938819.21 60
Iter: 2300 Obj: 57230898.61 59
Iter: 2350 Obj: 56520551.13 62
Iter: 2400 Obj: 56170577.54 60
Iter: 2450 Obj: 55840819.17 59
Iter: 2500 Obj: 55656218.31 56
Iter: 2550 Obj: 55310847.65 55
Iter: 2600 Obj: 55154237.23 60
Iter: 2650 Obj: 54914359.44 61
Iter: 2700 Obj: 54887740.79 64
Iter: 2750 Obj: 53226777.39 58
Iter: 2800 Obj: 52696277.40 63
Iter: 2850 Obj: 51591211.00 54
Iter: 2900 Obj: 50383252.67 62
Iter: 2950 Obj: 49352206.66 60
Iter: 3000 Obj: 48512276.57 60
```

```
Iter: 3050 Obj: 47803394.02 59
Iter: 3100 Obj: 47223200.98 51
Iter: 3150 Obj: 47012903.22 56
Iter: 3200 Obj: 46268656.75 58
Iter: 3250 Obj: 45455704.00 57
Iter: 3300 Obj: 45098376.12 56
Iter: 3350 Obj: 43940573.87 59
Iter: 3400 Obj: 43188898.79 64
Iter: 3450 Obj: 42917719.68 54
Iter: 3500 Obj: 42608908.97 60
Iter: 3550 Obj: 42224227.49 56
Iter: 3600 Obj: 42064380.58 58
Iter: 3650 Obj: 41973853.90 56
Iter: 3700 Obj: 41640964.46 64
Iter: 3750 Obj: 41575232.56 57
Iter: 3800 Obj: 41507067.88 56
Iter: 3850 Obj: 41365219.18 60
Iter: 3900 Obj: 41094797.90 60
Iter: 3950 Obj: 40794779.24 56
Iter: 4000 Obj: 40746076.18 55
Iter: 4050 Obj: 40666972.34 58
Iter: 4100 Obj: 40626922.68 57
Iter: 4150 Obj: 40617040.80 55
Iter: 4200 Obj: 40608878.70 51
Iter: 4250 Obj: 40405268.24 67
Iter: 4300 Obj: 40337863.22 57
Iter: 4350 Obj: 39797582.13 60
Iter: 4400 Obj: 39581470.02 56
Iter: 4450 Obj: 39366823.17 55
Iter: 4500 Obj: 39261078.74 55
Iter: 4550 Obj: 39085943.14 56
Iter: 4600 Obj: 38746831.66 60
Iter: 4650 Obj: 38327721.16 50
Iter: 4700 Obj: 38277307.12 59
Iter: 4750 Obj: 38245947.89 60
Iter: 4800 Obj: 38215208.53 57
Iter: 4850 Obj: 38161816.38 59
Iter: 4900 Obj: 38144805.61 57
Iter: 4950 Obj: 38112953.82 54
Iter: 5000 Obj: 38074142.18 57
Iter: 5050 Obj: 38054121.34 57
Iter: 5100 Obj: 38040309.86 57
Iter: 5150 Obj: 37916614.94 57
Iter: 5200 Obj: 37758636.82 50
Iter: 5250 Obj: 37484831.25 54
Iter: 5300 Obj: 37423712.41 55
Iter: 5350 Obj: 37292321.65 55
Iter: 5400 Obj: 37249481.62 53
Iter: 5450 Obj: 37194734.67 51
Iter: 5500 Obj: 37153863.12 54
Iter: 5550 Obj: 37126360.58 57
Iter: 5600 Obj: 37077405.53 52
Iter: 5650 Obj: 36701179.89 52
Iter: 5700 Obj: 36659215.60 52
Iter: 5750 Obj: 36623623.71 56
Iter: 5800 Obj: 36576080.84 50
Iter: 5850 Obj: 36554509.48 56
Iter: 5900 Obj: 36484584.01 57
Iter: 5950 Obj: 36451179.42 55
Iter: 6000 Obj: 36438383.34 58
```

```
Iter: 6050 Obj: 36387913.34 50
Iter: 6100 Obj: 36325588.19 53
Iter: 6150 Obj: 36264172.76 54
Iter: 6200 Obj: 36227548.93 56
Iter: 6250 Obj: 36194473.84 59
Iter: 6300 Obj: 36187445.02 52
Iter: 6350 Obj: 36174098.79 51
Iter: 6400 Obj: 36141868.54 52
Iter: 6450 Obj: 36119101.70 51
Iter: 6500 Obj: 36094976.16 53
Iter: 6550 Obj: 36056622.06 55
Iter: 6600 Obj: 36043124.80 52
Iter: 6650 Obj: 36012135.98 55
Iter: 6700 Obj: 35983037.83 55
Iter: 6750 Obj: 35973276.87 54
Iter: 6800 Obj: 35948334.15 53
Iter: 6850 Obj: 35937338.05 51
Iter: 6900 Obj: 35924511.06 57
Iter: 6950 Obj: 35907970.56 53
Iter: 7000 Obj: 35890522.40 53
Iter: 7050 Obj: 35875215.60 50
Iter: 7100 Obj: 35868351.43 51
Iter: 7150 Obj: 35832974.56 51
Iter: 7200 Obj: 35751759.88 51
Iter: 7250 Obj: 35736279.95 53
Iter: 7300 Obj: 35715669.59 54
Iter: 7350 Obj: 35650672.16 52
Iter: 7400 Obj: 35616357.28 59
Iter: 7450 Obj: 35580208.88 58
Iter: 7500 Obj: 35518182.39 51
Iter: 7550 Obj: 35502358.20 50
Iter: 7600 Obj: 35403099.78 52
Iter: 7650 Obj: 35050164.97 54
Iter: 7700 Obj: 35025569.61 53
Iter: 7750 Obj: 34985788.75 51
Iter: 7800 Obj: 34925120.72 52
Iter: 7850 Obj: 34894445.63 53
Iter: 7900 Obj: 34853398.01 52
Iter: 7950 Obj: 34827621.90 51
Iter: 8000 Obj: 34812719.57 51
Iter: 8050 Obj: 34781777.60 50
Iter: 8100 Obj: 34759477.74 53
Iter: 8150 Obj: 34748129.75 52
Iter: 8200 Obj: 34741119.06 51
Iter: 8250 Obj: 34729199.61 53
Iter: 8300 Obj: 34726991.53 51
Iter: 8350 Obj: 34724091.27 50
Iter: 8400 Obj: 34718245.20 51
Iter: 8450 Obj: 34715737.34 51
Iter: 8500 Obj: 34706328.86 50
Iter: 8550 Obj: 34701555.14 35
Iter: 8600 Obj: 34695216.61 15
Iter: 8650 Obj: 34692518.12 50

O P T I M A L   S O L U T I O N ---> OBJECTIVE 34692518.12
SOLVE TIME 00:00:32  ITER 8,667  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(10297)
--- Reading solution for model STORM1
```

< Metamodel 1 >

(Hot start)

TREQ down 10% (-1)    FREQ up 10% (+1)

```
GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD-10.TMP(360)
--- .FREQ10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- .YL.STM(4)
--- .XL.STM(135)
--- .DL.STM(395)
--- .TL.STM(82)
--- .D2L.STM(44)
--- .SL.STM(67)
--- .SLKL.STM(207)
--- .SLK2L.STM(30)
--- STORM.GMS(181)
--- Starting execution
--- STORM.GMS(11279)
--- Generating model STORM1
--- STORM.GMS(11280)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   All Rights Reserved Worldwide.
   Telephone 818-441-1565   FAX 818-441-1567

                    GAMS/XA Program Version 4.0 - Serial Number 501101
```

```
xa VERSION 10.00 DEC Alpha - VMS    USABLE MEMORY 15,999K BYTES
VARIABLES 7,448
   1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
CONSTRAINTS 1,834
   8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
   27,032 NON-ZEROS, WORK 1,322,629
MINIMIZATION.

Iter: 50 Inf:    839.72279 43
Iter: 100 Inf:    465.37219 32
Iter: 150 Inf:    265.38788 23
Iter: 200 Inf:     68.27628 15
Iter: 250 Inf:     51.60146 11
Iter: 300 Inf:      4.07031 2
Iter: 350 Inf:      3.87395 2
Iter: 400 Inf:      3.76839 1
Iter: 450 Obj: 171678780.0 68
Iter: 500 Obj: 165454018.0 66
Iter: 550 Obj: 164275074.6 61
Iter: 600 Obj: 161525591.9 67
Iter: 650 Obj: 149655999.9 63
Iter: 700 Obj: 148342923.2 61
Iter: 750 Obj: 145045994.7 64
Iter: 800 Obj: 141158222.4 63
Iter: 850 Obj: 139245401.8 68
Iter: 900 Obj: 136445518.1 64
Iter: 950 Obj: 132098238.4 60
Iter: 1000 Obj: 127483401.4 61
Iter: 1050 Obj: 125892975.1 66
Iter: 1100 Obj: 123886386.9 61
Iter: 1150 Obj: 119877139.4 66
Iter: 1200 Obj: 117882219.0 66
Iter: 1250 Obj: 116300790.9 61
Iter: 1300 Obj: 109212210.3 58
Iter: 1350 Obj: 100990494.2 64
Iter: 1400 Obj: 97192504.57 56
Iter: 1450 Obj: 95531282.03 62
Iter: 1500 Obj: 93225307.87 57
Iter: 1550 Obj: 86050990.59 61
Iter: 1600 Obj: 80802072.02 59
Iter: 1650 Obj: 80229245.55 62
Iter: 1700 Obj: 78055324.74 58
Iter: 1750 Obj: 77506019.16 63
Iter: 1800 Obj: 76226151.14 61
Iter: 1850 Obj: 75969824.80 59
Iter: 1900 Obj: 75476989.41 57
Iter: 1950 Obj: 73619637.80 50
Iter: 2000 Obj: 66729915.90 57
Iter: 2050 Obj: 58193411.37 62
Iter: 2100 Obj: 56187294.79 59
Iter: 2150 Obj: 55715027.27 58
Iter: 2200 Obj: 54303220.37 61
Iter: 2250 Obj: 52604491.11 61
Iter: 2300 Obj: 52191252.59 57
Iter: 2350 Obj: 51265954.70 57
Iter: 2400 Obj: 50531098.06 58
Iter: 2450 Obj: 50101509.12 55
Iter: 2500 Obj: 48414563.46 57
Iter: 2550 Obj: 47364949.17 57
Iter: 2600 Obj: 47240593.72 60
```

```
Iter: 2650 Obj: 46638964.99 60
Iter: 2700 Obj: 45132645.51 58
Iter: 2750 Obj: 44547941.97 58
Iter: 2800 Obj: 43058023.68 59
Iter: 2850 Obj: 42860269.40 54
Iter: 2900 Obj: 42612507.58 62
Iter: 2950 Obj: 42078291.00 57
Iter: 3000 Obj: 42026076.12 63
Iter: 3050 Obj: 41727179.31 58
Iter: 3100 Obj: 41539429.87 56
Iter: 3150 Obj: 41504133.71 61
Iter: 3200 Obj: 41394497.58 56
Iter: 3250 Obj: 41344568.50 52
Iter: 3300 Obj: 41279871.70 59
Iter: 3350 Obj: 41180815.15 57
Iter: 3400 Obj: 41078017.04 53
Iter: 3450 Obj: 40808087.72 61
Iter: 3500 Obj: 40511754.45 58
Iter: 3550 Obj: 40396262.85 53
Iter: 3600 Obj: 40335197.43 62
Iter: 3650 Obj: 40316211.00 53
Iter: 3700 Obj: 40175747.57 58
Iter: 3750 Obj: 40091233.78 53
Iter: 3800 Obj: 40036779.11 58
Iter: 3850 Obj: 40000810.73 56
Iter: 3900 Obj: 39874791.18 54
Iter: 3950 Obj: 39343031.89 54
Iter: 4000 Obj: 39097138.20 56
Iter: 4050 Obj: 38901791.11 52
Iter: 4100 Obj: 38842167.20 58
Iter: 4150 Obj: 38564327.75 56
Iter: 4200 Obj: 38360841.92 54
Iter: 4250 Obj: 38202103.56 62
Iter: 4300 Obj: 38049744.26 55
Iter: 4350 Obj: 37927072.07 52
Iter: 4400 Obj: 37585380.23 51
Iter: 4450 Obj: 37480405.68 56
Iter: 4500 Obj: 37395637.66 56
Iter: 4550 Obj: 37306554.06 57
Iter: 4600 Obj: 37175163.64 60
Iter: 4650 Obj: 37036242.39 55
Iter: 4700 Obj: 36950591.26 54
Iter: 4750 Obj: 36808352.62 50
Iter: 4800 Obj: 36746835.44 53
Iter: 4850 Obj: 36508067.07 56
Iter: 4900 Obj: 36383075.81 55
Iter: 4950 Obj: 36338333.72 53
Iter: 5000 Obj: 36210862.16 52
Iter: 5050 Obj: 36172334.79 55
Iter: 5100 Obj: 36097697.88 56
Iter: 5150 Obj: 36038483.94 52
Iter: 5200 Obj: 35955603.16 50
Iter: 5250 Obj: 35866554.53 50
Iter: 5300 Obj: 35834710.21 51
Iter: 5350 Obj: 35761907.71 51
Iter: 5400 Obj: 35744623.82 53
Iter: 5450 Obj: 35724064.19 52
Iter: 5500 Obj: 35641198.35 53
Iter: 5550 Obj: 35619237.96 53
Iter: 5600 Obj: 35611632.17 53
```

```
Iter: 5650 Obj: 35519172.93 52
Iter: 5700 Obj: 35432883.53 52
Iter: 5750 Obj: 35343770.18 51
Iter: 5800 Obj: 35264880.32 53
Iter: 5850 Obj: 35224240.93 50
Iter: 5900 Obj: 35143481.27 52
Iter: 5950 Obj: 35117093.80 50
Iter: 6000 Obj: 34966942.92 53
Iter: 6050 Obj: 34957024.52 52
Iter: 6100 Obj: 34912665.25 50
Iter: 6150 Obj: 34903260.56 51
Iter: 6200 Obj: 34884877.82 52
Iter: 6250 Obj: 34868145.45 53
Iter: 6300 Obj: 34863403.25 51
Iter: 6350 Obj: 34860318.62 52
Iter: 6400 Obj: 34856555.21 52
Iter: 6450 Obj: 34842988.70 53
Iter: 6500 Obj: 34820633.55 53
Iter: 6550 Obj: 34814945.31 51
Iter: 6600 Obj: 34812464.19 50
Iter: 6650 Obj: 34802537.84 51
Iter: 6700 Obj: 34779843.82 50
Iter: 6750 Obj: 34767384.65 50
Iter: 6800 Obj: 34753117.00 51
Iter: 6850 Obj: 34746483.98 50
Iter: 6900 Obj: 34745327.13 52
Iter: 6950 Obj: 34742063.83 51
Iter: 7000 Obj: 34731170.03 50
Iter: 7050 Obj: 34726197.36 48
Iter: 7100 Obj: 34716835.56 41
Iter: 7150 Obj: 34703931.06 55
Iter: 7200 Obj: 34701167.65 42
Iter: 7250 Obj: 34698085.31 14
Iter: 7300 Obj: 34692522.59 7

O P T I M A L   S O L U T I O N ---> OBJECTIVE 34692518.12
SOLVE TIME 00:00:30  ITER 7,326  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(11280)
--- Reading solution for model STORM1
--- STORM.GMS(11281)
--- All done
```

< Metamodel 1 >

TREQ up 10% (+1)    FREQ down 10% (-1)

```
=======================================

GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD10.TMP(360)
--- .FREQ-10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- STORM.GMS(162)
--- Starting execution
--- STORM.GMS(10296)
--- Generating model STORM1
--- STORM.GMS(10297)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   Telephone 818-441-1565   FAX 818-441-1567

                    GAMS/XA Program Version 4.0 - Serial Number 501101

STATISTICS - GAMS Fri Feb 14 22:26:36 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.

Iter: 50 Inf:   753.12297 44
```

```
Iter: 100 Inf:   355.41336 33
Iter: 150 Inf:    84.23718 17
Iter: 200 Inf:    42.30848 9
Iter: 250 Inf:     3.08323 1
Iter: 300 Inf:     3.08323 1
Iter: 350 Obj: 210299063.4 60
Iter: 400 Obj: 202815349.3 68
Iter: 450 Obj: 193948078.0 67
Iter: 500 Obj: 183592065.8 63
Iter: 550 Obj: 173994350.5 66
Iter: 600 Obj: 169882907.4 63
Iter: 650 Obj: 168769118.6 68
Iter: 700 Obj: 164756945.1 62
Iter: 750 Obj: 164157633.4 60
Iter: 800 Obj: 158664729.6 62
Iter: 850 Obj: 157928853.7 66
Iter: 900 Obj: 155827710.0 64
Iter: 950 Obj: 155405521.3 64
Iter: 1000 Obj: 152146842.0 61
Iter: 1050 Obj: 151709819.1 60
Iter: 1100 Obj: 146503593.8 60
Iter: 1150 Obj: 142686391.3 63
Iter: 1200 Obj: 140197648.2 68
Iter: 1250 Obj: 133269619.7 60
Iter: 1300 Obj: 132182988.7 55
Iter: 1350 Obj: 131287689.3 61
Iter: 1400 Obj: 130139991.2 61
Iter: 1450 Obj: 119451135.0 62
Iter: 1500 Obj: 117511020.3 62
Iter: 1550 Obj: 114820221.5 63
Iter: 1600 Obj: 113815600.8 60
Iter: 1650 Obj: 112143714.6 61
Iter: 1700 Obj: 103702266.4 58
Iter: 1750 Obj: 95311182.96 61
Iter: 1800 Obj: 89362293.53 56
Iter: 1850 Obj: 86009331.94 57
Iter: 1900 Obj: 83912165.08 55
Iter: 1950 Obj: 79612932.26 66
Iter: 2000 Obj: 73025661.57 60
Iter: 2050 Obj: 72501916.47 61
Iter: 2100 Obj: 70799733.21 64
Iter: 2150 Obj: 70535872.18 58
Iter: 2200 Obj: 69825324.61 59
Iter: 2250 Obj: 69416418.85 66
Iter: 2300 Obj: 69114753.50 59
Iter: 2350 Obj: 68147429.09 66
Iter: 2400 Obj: 67062154.82 56
Iter: 2450 Obj: 61447703.45 64
Iter: 2500 Obj: 60917506.03 58
Iter: 2550 Obj: 59749349.76 51
Iter: 2600 Obj: 59061041.32 62
Iter: 2650 Obj: 58809287.20 68
Iter: 2700 Obj: 58590808.58 59
Iter: 2750 Obj: 58392138.44 64
Iter: 2800 Obj: 57981415.28 61
Iter: 2850 Obj: 57458826.80 60
Iter: 2900 Obj: 56026541.16 52
Iter: 2950 Obj: 54069176.06 54
Iter: 3000 Obj: 53745401.34 60
Iter: 3050 Obj: 53533020.71 60
```

```
Iter: 3100 Obj: 53435924.77 55
Iter: 3150 Obj: 53288486.47 54
Iter: 3200 Obj: 53165772.19 61
Iter: 3250 Obj: 52982041.40 61
Iter: 3300 Obj: 52350870.46 54
Iter: 3350 Obj: 52009115.95 51
Iter: 3400 Obj: 51594232.10 59
Iter: 3450 Obj: 50977497.87 53
Iter: 3500 Obj: 50659324.64 52
Iter: 3550 Obj: 49547683.39 58
Iter: 3600 Obj: 48976581.55 57
Iter: 3650 Obj: 48727794.38 57
Iter: 3700 Obj: 48601342.23 57
Iter: 3750 Obj: 48466361.71 58
Iter: 3800 Obj: 48360699.07 52
Iter: 3850 Obj: 48310398.28 53
Iter: 3900 Obj: 48244722.17 54
Iter: 3950 Obj: 48157975.20 56
Iter: 4000 Obj: 47960303.96 59
Iter: 4050 Obj: 47894955.65 57
Iter: 4100 Obj: 47828359.33 58
Iter: 4150 Obj: 47702810.36 60
Iter: 4200 Obj: 47554652.57 54
Iter: 4250 Obj: 47514739.02 61
Iter: 4300 Obj: 47457763.96 57
Iter: 4350 Obj: 47395971.29 51
Iter: 4400 Obj: 47320045.30 55
Iter: 4450 Obj: 47267874.26 55
Iter: 4500 Obj: 47154932.14 61
Iter: 4550 Obj: 47009210.28 52
Iter: 4600 Obj: 46898494.72 52
Iter: 4650 Obj: 46810412.06 51
Iter: 4700 Obj: 46259836.87 55
Iter: 4750 Obj: 46202203.59 55
Iter: 4800 Obj: 46094556.97 54
Iter: 4850 Obj: 45911932.99 55
Iter: 4900 Obj: 45778384.64 64
Iter: 4950 Obj: 45648096.39 63
Iter: 5000 Obj: 45525734.89 59
Iter: 5050 Obj: 45448147.74 53
Iter: 5100 Obj: 45369996.63 58
Iter: 5150 Obj: 45079776.17 62
Iter: 5200 Obj: 44918132.22 59
Iter: 5250 Obj: 44847150.68 52
Iter: 5300 Obj: 44723132.65 58
Iter: 5350 Obj: 44526599.02 56
Iter: 5400 Obj: 44490180.47 55
Iter: 5450 Obj: 44436890.33 60
Iter: 5500 Obj: 44308033.46 63
Iter: 5550 Obj: 44254405.88 59
Iter: 5600 Obj: 44207977.08 56
Iter: 5650 Obj: 44071174.81 58
Iter: 5700 Obj: 44002376.43 53
Iter: 5750 Obj: 43936049.16 57
Iter: 5800 Obj: 43841368.84 55
Iter: 5850 Obj: 43787102.96 60
Iter: 5900 Obj: 43741807.01 54
Iter: 5950 Obj: 43703723.70 57
Iter: 6000 Obj: 43673385.03 50
Iter: 6050 Obj: 43653156.39 61
```

```
Iter: 6100 Obj: 43642320.56 60
Iter: 6150 Obj: 43625083.69 56
Iter: 6200 Obj: 43605129.03 57
Iter: 6250 Obj: 43503455.40 63
Iter: 6300 Obj: 43429080.57 60
Iter: 6350 Obj: 43338880.59 55
Iter: 6400 Obj: 43267588.70 50
Iter: 6450 Obj: 43193566.48 53
Iter: 6500 Obj: 43163078.13 52
Iter: 6550 Obj: 43121031.15 52
Iter: 6600 Obj: 43077154.42 56
Iter: 6650 Obj: 43062978.64 60
Iter: 6700 Obj: 43049314.19 53
Iter: 6750 Obj: 43028853.59 56
Iter: 6800 Obj: 43008728.14 57
Iter: 6850 Obj: 42929712.84 53
Iter: 6900 Obj: 42818417.98 51
Iter: 6950 Obj: 42790839.91 52
Iter: 7000 Obj: 42749680.11 51
Iter: 7050 Obj: 42595552.96 54
Iter: 7100 Obj: 42511580.35 53
Iter: 7150 Obj: 42457361.18 53
Iter: 7200 Obj: 42434994.02 55
Iter: 7250 Obj: 42423564.85 53
Iter: 7300 Obj: 42333333.80 53
Iter: 7350 Obj: 42228506.99 54
Iter: 7400 Obj: 42206683.43 54
Iter: 7450 Obj: 42164425.22 54
Iter: 7500 Obj: 42135977.79 53
Iter: 7550 Obj: 42120622.97 50
Iter: 7600 Obj: 42088795.74 52
Iter: 7650 Obj: 42081933.29 50
Iter: 7700 Obj: 42072215.07 56
Iter: 7750 Obj: 42053437.30 56
Iter: 7800 Obj: 42003123.46 56
Iter: 7850 Obj: 41986941.34 59
Iter: 7900 Obj: 41973497.36 58
Iter: 7950 Obj: 41964179.12 51
Iter: 8000 Obj: 41956248.16 56
Iter: 8050 Obj: 41946968.48 51
Iter: 8100 Obj: 41940950.82 54
Iter: 8150 Obj: 41922702.75 56
Iter: 8200 Obj: 41881577.46 58
Iter: 8250 Obj: 41843391.27 52
Iter: 8300 Obj: 41722332.05 53
Iter: 8350 Obj: 41705543.98 58
Iter: 8400 Obj: 41691831.28 53
Iter: 8450 Obj: 41651347.07 53
Iter: 8500 Obj: 41636308.76 51
Iter: 8550 Obj: 41610931.14 52
Iter: 8600 Obj: 41596941.16 58
Iter: 8650 Obj: 41576751.98 51
Iter: 8700 Obj: 41442510.42 51
Iter: 8750 Obj: 41432737.24 52
Iter: 8800 Obj: 41408540.79 53
Iter: 8850 Obj: 41329257.56 50
Iter: 8900 Obj: 41303212.72 55
Iter: 8950 Obj: 41257036.44 51
Iter: 9000 Obj: 41249377.63 50
Iter: 9050 Obj: 41199232.22 54
```

```
Iter: 9100 Obj: 41182042.30 52
Iter: 9150 Obj: 41131021.45 53
Iter: 9200 Obj: 41084683.54 53
Iter: 9250 Obj: 41061975.04 54
Iter: 9300 Obj: 41047981.14 51
Iter: 9350 Obj: 41019601.56 52
Iter: 9400 Obj: 41009137.51 53
Iter: 9450 Obj: 40959539.60 52
Iter: 9500 Obj: 40911655.47 51
Iter: 9550 Obj: 40882582.18 52
Iter: 9600 Obj: 40863846.50 52
Iter: 9650 Obj: 40740908.56 56
Iter: 9700 Obj: 40729671.47 50
Iter: 9750 Obj: 40675188.04 50
Iter: 9800 Obj: 40670834.45 53
Iter: 9850 Obj: 40667563.59 52
Iter: 9900 Obj: 40662640.79 50
Iter: 9950 Obj: 40619533.97 50
Iter: 10000 Obj: 40604784.11 50
Iter: 10050 Obj: 40590864.67 20
Iter: 10100 Obj: 40570074.20 19
Iter: 10150 Obj: 40567833.21 50

O P T I M A L   S O L U T I O N ---> OBJECTIVE 40567833.21
SOLVE TIME 00:00:46  ITER 10,169  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(10297)
--- Reading solution for model STORM1
--- STORM.GMS(10298)
--- All done
```

< Metamodel 1 >

(Hot start)

TREQ up 10% (+1)    FREQ down 10% (-1)

```
GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                 G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD10.TMP(360)
--- .FREQ-10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- .YL.STM(4)
--- .XL.STM(135)
--- .DL.STM(395)
--- .TL.STM(82)
--- .D2L.STM(44)
--- .SL.STM(67)
--- .SLKL.STM(207)
--- .SLK2L.STM(30)
--- STORM.GMS(181)
--- Starting execution
--- STORM.GMS(11279)
--- Generating model STORM1
--- STORM.GMS(11280)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   San Marino, California  91108   U.S.A.
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   Telephone 818-441-1565   FAX 818-441-1567
```

```
STATISTICS - GAMS Fri Feb 14 23:45:40 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.


Iter: 50 Inf:   690.08052 49
Iter: 100 Inf:   537.48969 33
Iter: 150 Inf:   211.59935 25
Iter: 200 Inf:   134.95141 25
Iter: 250 Inf:    90.72038 18
Iter: 300 Inf:    26.80856 7
Iter: 350 Inf:     3.08323 1
Iter: 400 Inf:     0.00000 0
Iter: 450 Obj: 198235506.8 64
Iter: 500 Obj: 197314376.9 64
Iter: 550 Obj: 194700258.2 64
Iter: 600 Obj: 193049031.6 68
Iter: 650 Obj: 191249885.8 70
Iter: 700 Obj: 178971359.0 57
Iter: 750 Obj: 175002773.2 65
Iter: 800 Obj: 171997747.3 59
Iter: 850 Obj: 169366129.3 65
Iter: 900 Obj: 164841919.1 71
Iter: 950 Obj: 162305506.1 64
Iter: 1000 Obj: 161971983.7 66
Iter: 1050 Obj: 158717303.8 65
Iter: 1100 Obj: 158420968.8 60
Iter: 1150 Obj: 155262796.6 62
Iter: 1200 Obj: 151059989.6 65
Iter: 1250 Obj: 138033703.4 63
Iter: 1300 Obj: 131639013.0 66
Iter: 1350 Obj: 129463540.8 58
Iter: 1400 Obj: 128058451.6 66
Iter: 1450 Obj: 126826656.8 62
Iter: 1500 Obj: 125399644.0 53
Iter: 1550 Obj: 124342413.3 63
Iter: 1600 Obj: 123005614.9 69
Iter: 1650 Obj: 122430196.6 56
Iter: 1700 Obj: 120057952.0 61
Iter: 1750 Obj: 113584585.2 63
Iter: 1800 Obj: 110515040.8 57
Iter: 1850 Obj: 100699086.9 64
Iter: 1900 Obj: 94939936.89 58
Iter: 1950 Obj: 89820002.48 61
Iter: 2000 Obj: 88209397.97 63
Iter: 2050 Obj: 86405737.72 55
Iter: 2100 Obj: 76864423.93 61
Iter: 2150 Obj: 75391869.02 65
Iter: 2200 Obj: 74545242.06 63
Iter: 2250 Obj: 73777585.98 63
Iter: 2300 Obj: 73496205.93 62
Iter: 2350 Obj: 72607476.40 57
Iter: 2400 Obj: 69579905.77 57
Iter: 2450 Obj: 68096926.25 61
```

```
Iter: 2500 Obj: 66248343.76 55
Iter: 2550 Obj: 62162451.56 61
Iter: 2600 Obj: 60798077.86 60
Iter: 2650 Obj: 59682712.57 57
Iter: 2700 Obj: 59009766.89 60
Iter: 2750 Obj: 58643619.07 60
Iter: 2800 Obj: 58150305.86 58
Iter: 2850 Obj: 57539184.99 57
Iter: 2900 Obj: 57132130.74 57
Iter: 2950 Obj: 56823898.57 60
Iter: 3000 Obj: 56522587.63 57
Iter: 3050 Obj: 55310147.05 61
Iter: 3100 Obj: 54654993.06 54
Iter: 3150 Obj: 54316999.14 62
Iter: 3200 Obj: 53603259.89 51
Iter: 3250 Obj: 53297080.18 52
Iter: 3300 Obj: 53040362.77 60
Iter: 3350 Obj: 52877331.77 61
Iter: 3400 Obj: 52451118.01 53
Iter: 3450 Obj: 50875701.06 58
Iter: 3500 Obj: 50213479.58 63
Iter: 3550 Obj: 49847775.33 58
Iter: 3600 Obj: 49112780.76 56
Iter: 3650 Obj: 48890894.43 55
Iter: 3700 Obj: 48748364.15 53
Iter: 3750 Obj: 48624978.09 57
Iter: 3800 Obj: 47524629.86 59
Iter: 3850 Obj: 47260078.26 61
Iter: 3900 Obj: 46752566.62 60
Iter: 3950 Obj: 46228807.36 55
Iter: 4000 Obj: 46138566.54 56
Iter: 4050 Obj: 46019354.89 56
Iter: 4100 Obj: 45770170.46 61
Iter: 4150 Obj: 45672697.53 58
Iter: 4200 Obj: 45539683.95 54
Iter: 4250 Obj: 45465926.29 57
Iter: 4300 Obj: 45340601.98 55
Iter: 4350 Obj: 45108317.54 56
Iter: 4400 Obj: 45016504.86 57
Iter: 4450 Obj: 44990154.11 54
Iter: 4500 Obj: 44921786.26 59
Iter: 4550 Obj: 44699028.65 55
Iter: 4600 Obj: 44694558.92 58
Iter: 4650 Obj: 44679766.49 52
Iter: 4700 Obj: 44609785.90 56
Iter: 4750 Obj: 44339408.59 60
Iter: 4800 Obj: 44307331.74 55
Iter: 4850 Obj: 44167898.79 52
Iter: 4900 Obj: 43761876.94 52
Iter: 4950 Obj: 43040126.22 60
Iter: 5000 Obj: 42958768.36 56
Iter: 5050 Obj: 42944880.70 57
Iter: 5100 Obj: 42678379.04 52
Iter: 5150 Obj: 42464291.76 55
Iter: 5200 Obj: 42424541.40 58
Iter: 5250 Obj: 42050662.53 52
Iter: 5300 Obj: 41997280.56 54
Iter: 5350 Obj: 41931418.51 55
Iter: 5400 Obj: 41882742.73 53
Iter: 5450 Obj: 41848685.73 50
```

```
Iter: 5500 Obj: 41766635.41 51
Iter: 5550 Obj: 41737800.07 56
Iter: 5600 Obj: 41643607.43 50
Iter: 5650 Obj: 41526414.30 52
Iter: 5700 Obj: 41509385.28 54
Iter: 5750 Obj: 41454027.21 52
Iter: 5800 Obj: 41393998.10 52
Iter: 5850 Obj: 41300058.53 52
Iter: 5900 Obj: 41251858.25 55
Iter: 5950 Obj: 41207621.07 55
Iter: 6000 Obj: 41182144.12 57
Iter: 6050 Obj: 41169028.42 52
Iter: 6100 Obj: 41145703.45 51
Iter: 6150 Obj: 41119771.87 51
Iter: 6200 Obj: 41031208.92 50
Iter: 6250 Obj: 41027546.16 53
Iter: 6300 Obj: 40940241.49 50
Iter: 6350 Obj: 40911941.68 51
Iter: 6400 Obj: 40780965.89 50
Iter: 6450 Obj: 40759109.16 50
Iter: 6500 Obj: 40742179.31 51
Iter: 6550 Obj: 40718912.87 50
Iter: 6600 Obj: 40697319.88 51
Iter: 6650 Obj: 40684932.03 51
Iter: 6700 Obj: 40679737.86 50
Iter: 6750 Obj: 40667622.17 50
Iter: 6800 Obj: 40663713.20 51
Iter: 6850 Obj: 40659045.32 50
Iter: 6900 Obj: 40654868.75 50
Iter: 6950 Obj: 40624872.55 52
Iter: 7000 Obj: 40621141.17 51
Iter: 7050 Obj: 40617602.73 50
Iter: 7100 Obj: 40597117.28 50
Iter: 7150 Obj: 40583266.48 51
Iter: 7200 Obj: 40576258.83 47
Iter: 7250 Obj: 40573547.52 47
Iter: 7300 Obj: 40572395.52 42
Iter: 7350 Obj: 40567944.48 17
Iter: 7400 Obj: 40567833.21 18


O P T I M A L   S O L U T I O N ---> OBJECTIVE 40567833.21
SOLVE TIME 00:00:28  ITER 7,400  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(11280)
--- Reading solution for model STORM1
--- STORM.GMS(11281)
--- All done
```

< Metamodel 1 >

TREQ up 10% (+1)   FREQ up 10% (+1)

```
=====================================
GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology                G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD10.TMP(360)
--- .FREQ10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- STORM.GMS(162)
--- Starting execution
--- STORM.GMS(10296)
--- Generating model STORM1
--- STORM.GMS(10297)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   Telephone 818-441-1565   FAX 818-441-1567

                         GAMS/XA Program Version 4.0 - Serial Number 501101

STATISTICS - GAMS Fri Feb 14 22:29:04 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.
```

```
Iter: 50 Inf:   869.23189 49
Iter: 100 Inf:   479.43776 37
Iter: 150 Inf:   296.62448 25
Iter: 200 Inf:   126.56623 18
Iter: 250 Inf:    50.64685 10
Iter: 300 Inf:    11.67880 4
Iter: 350 Inf:     3.76839 1
Iter: 400 Inf:     3.76839 1
Iter: 450 Obj: 200170948.6 68
Iter: 500 Obj: 191638944.2 67
Iter: 550 Obj: 181322999.0 59
Iter: 600 Obj: 180667312.7 60
Iter: 650 Obj: 176080333.4 68
Iter: 700 Obj: 174649663.6 69
Iter: 750 Obj: 171994120.7 65
Iter: 800 Obj: 170374443.8 61
Iter: 850 Obj: 151987168.2 67
Iter: 900 Obj: 150756102.5 71
Iter: 950 Obj: 146917787.1 66
Iter: 1000 Obj: 144769962.9 66
Iter: 1050 Obj: 143109864.6 63
Iter: 1100 Obj: 142260571.2 62
Iter: 1150 Obj: 140320252.2 66
Iter: 1200 Obj: 136265000.7 61
Iter: 1250 Obj: 130921451.3 66
Iter: 1300 Obj: 126067266.2 63
Iter: 1350 Obj: 124905791.8 58
Iter: 1400 Obj: 122183614.7 67
Iter: 1450 Obj: 120893151.8 63
Iter: 1500 Obj: 118131574.0 69
Iter: 1550 Obj: 114195851.1 63
Iter: 1600 Obj: 103063873.9 55
Iter: 1650 Obj: 99958373.52 60
Iter: 1700 Obj: 94826576.89 53
Iter: 1750 Obj: 92023126.79 69
Iter: 1800 Obj: 89787751.93 66
Iter: 1850 Obj: 79870642.62 59
Iter: 1900 Obj: 76094210.91 62
Iter: 1950 Obj: 68651489.70 55
Iter: 2000 Obj: 67474901.91 59
Iter: 2050 Obj: 64184686.25 61
Iter: 2100 Obj: 63599098.99 56
Iter: 2150 Obj: 63321399.59 60
Iter: 2200 Obj: 59844306.53 59
Iter: 2250 Obj: 58790278.57 55
Iter: 2300 Obj: 57513942.28 54
Iter: 2350 Obj: 56172084.29 59
Iter: 2400 Obj: 55256702.39 64
Iter: 2450 Obj: 54793757.20 58
Iter: 2500 Obj: 53842436.75 64
Iter: 2550 Obj: 53269076.15 57
Iter: 2600 Obj: 52819545.74 60
Iter: 2650 Obj: 52605579.30 60
Iter: 2700 Obj: 52196856.68 53
Iter: 2750 Obj: 51821759.48 61
Iter: 2800 Obj: 51643858.89 62
Iter: 2850 Obj: 51521152.74 62
Iter: 2900 Obj: 51380300.66 55
Iter: 2950 Obj: 51126278.30 60
```

```
Iter: 3000 Obj: 50639864.68 60
Iter: 3050 Obj: 50297076.82 59
Iter: 3100 Obj: 49935195.69 60
Iter: 3150 Obj: 49607650.27 58
Iter: 3200 Obj: 49257889.87 58
Iter: 3250 Obj: 48830159.98 50
Iter: 3300 Obj: 48492420.00 52
Iter: 3350 Obj: 47823865.30 55
Iter: 3400 Obj: 47541017.08 59
Iter: 3450 Obj: 47424669.96 63
Iter: 3500 Obj: 47312928.28 57
Iter: 3550 Obj: 47269837.85 61
Iter: 3600 Obj: 47232712.74 62
Iter: 3650 Obj: 47193535.46 54
Iter: 3700 Obj: 47146872.20 62
Iter: 3750 Obj: 47061791.34 57
Iter: 3800 Obj: 46622229.57 59
Iter: 3850 Obj: 46530690.55 51
Iter: 3900 Obj: 46173221.28 56
Iter: 3950 Obj: 45794945.46 60
Iter: 4000 Obj: 45543137.05 57
Iter: 4050 Obj: 45386922.04 54
Iter: 4100 Obj: 45111746.51 54
Iter: 4150 Obj: 45076836.26 58
Iter: 4200 Obj: 44978567.34 58
Iter: 4250 Obj: 44268952.88 58
Iter: 4300 Obj: 44138779.85 54
Iter: 4350 Obj: 44038683.52 55
Iter: 4400 Obj: 43942576.31 58
Iter: 4450 Obj: 43780643.86 61
Iter: 4500 Obj: 43732329.58 51
Iter: 4550 Obj: 43686603.83 52
Iter: 4600 Obj: 43572406.85 58
Iter: 4650 Obj: 43410790.31 54
Iter: 4700 Obj: 43355332.01 56
Iter: 4750 Obj: 43338192.63 56
Iter: 4800 Obj: 43257130.95 55
Iter: 4850 Obj: 43207841.58 55
Iter: 4900 Obj: 43155556.63 50
Iter: 4950 Obj: 43134367.48 52
Iter: 5000 Obj: 43129711.57 57
Iter: 5050 Obj: 43109637.50 51
Iter: 5100 Obj: 43079976.03 57
Iter: 5150 Obj: 43068263.35 54
Iter: 5200 Obj: 42978856.15 55
Iter: 5250 Obj: 42956165.00 58
Iter: 5300 Obj: 42929439.31 51
Iter: 5350 Obj: 42831029.83 59
Iter: 5400 Obj: 42780157.99 56
Iter: 5450 Obj: 42761078.00 50
Iter: 5500 Obj: 42746653.96 60
Iter: 5550 Obj: 42699061.56 55
Iter: 5600 Obj: 42608776.20 51
Iter: 5650 Obj: 42530832.08 53
Iter: 5700 Obj: 42490125.85 58
Iter: 5750 Obj: 42472835.91 53
Iter: 5800 Obj: 42453379.58 51
Iter: 5850 Obj: 42393200.48 54
Iter: 5900 Obj: 42330168.66 50
Iter: 5950 Obj: 42280045.85 55
```

```
Iter: 6000 Obj: 42257260.24 55
Iter: 6050 Obj: 42184000.43 53
Iter: 6100 Obj: 42180768.83 54
Iter: 6150 Obj: 41998886.57 53
Iter: 6200 Obj: 41970648.48 50
Iter: 6250 Obj: 41912204.43 54
Iter: 6300 Obj: 41904813.08 52
Iter: 6350 Obj: 41895743.13 55
Iter: 6400 Obj: 41871228.59 52
Iter: 6450 Obj: 41843794.73 51
Iter: 6500 Obj: 41816690.85 50
Iter: 6550 Obj: 41794088.29 51
Iter: 6600 Obj: 41767261.85 51
Iter: 6650 Obj: 41743673.35 50
Iter: 6700 Obj: 41675404.65 51
Iter: 6750 Obj: 41626277.47 53
Iter: 6800 Obj: 41605875.36 52
Iter: 6850 Obj: 41569514.95 51
Iter: 6900 Obj: 41501352.70 51
Iter: 6950 Obj: 41491003.31 50
Iter: 7000 Obj: 41465674.00 50
Iter: 7050 Obj: 41455022.73 51
Iter: 7100 Obj: 41448913.82 50
Iter: 7150 Obj: 41417190.78 51
Iter: 7200 Obj: 41408778.56 51
Iter: 7250 Obj: 41399173.77 35
Iter: 7300 Obj: 41359269.84 35
Iter: 7350 Obj: 41355977.30 35
Iter: 7400 Obj: 41352674.22 10
Iter: 7450 Obj: 41351275.00 7

O P T I M A L   S O L U T I O N ---> OBJECTIVE 41351256.59
SOLVE TIME 00:00:32  ITER 7,476  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(10297)
--- Reading solution for model STORM1
--- STORM.GMS(10298)
--- All done
```

< Metamodel 1 >

(Hot start)

TREQ up 10% (+1)   FREQ up 10% (+1)

```
=====================================

GAMS 2.25.087 (c) Copyright 1994 GAMS Development Corp. All rights reserved
Licensee: Air Force Institute of Technology               G960423:1007As-AXV
          Wright-Patterson AFB, Ohio
--- Starting compilation
--- .PLANES.STM(8)
--- .ROUTE.TMP(1)
--- .BASES.STM(182)
--- .TRANS.TMP(121)
--- .D.VAR(1750)
--- .S.VAR(905)
--- .T.VAR(2494)
--- .ONROUTE.TMP(2762)
--- .START.TMP(5)
--- .ENDS.TMP(5)
--- .LENGTHS.TMP(233)
--- .VISITS.TMP(915)
--- .LOAD10.TMP(360)
--- .FREQ10.TMP(151)
--- .TIMES.STM(234)
--- .MISC.STM(9)
--- .LX.STM(1)
--- .YL.STM(4)
--- .XL.STM(135)
--- .DL.STM(395)
--- .TL.STM(82)
--- .D2L.STM(44)
--- .SL.STM(67)
--- .SLKL.STM(207)
--- .SLK2L.STM(30)
--- STORM.GMS(181)
--- Starting execution
--- STORM.GMS(11279)
--- Generating model STORM1
--- STORM.GMS(11280)
---    1833 rows, 7448 columns, and 27031 non-zeroes.
--- Executing XA
 ...Reading Header.
 ...Reading Rows.
 ...Reading Columns.
 ...Input complete.
 ...XA Memory Request 16MB.

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   San Marino, California  91108   U.S.A.
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```

```
STATISTICS - GAMS Fri Feb 14 23:47:54 1997
  xa VERSION 10.00 DEC Alpha - VMS   USABLE MEMORY 15,999K BYTES
  VARIABLES 7,448
     1 LOWER, 0 FIXED, 0 UPPER, 1 FREE,
  CONSTRAINTS 1,834
     8 GE, 1,306 EQ, 519 LE, 1 NULL/FREE, 0 RANGED.
     27,032 NON-ZEROS, WORK 1,322,629
  MINIMIZATION.


Iter: 50 Inf:   852.65266 49
Iter: 100 Inf:   665.24167 32
Iter: 150 Inf:   309.12670 25
Iter: 200 Inf:   132.67594 18
Iter: 250 Inf:    26.04604 7
Iter: 300 Inf:    10.84092 3
Iter: 350 Inf:     3.76839 1
Iter: 400 Inf:     0.00000 0
Iter: 450 Obj: 208304071.3 72
Iter: 500 Obj: 202741474.1 64
Iter: 550 Obj: 198071058.8 69
Iter: 600 Obj: 192859775.8 69
Iter: 650 Obj: 191418640.5 63
Iter: 700 Obj: 185410260.6 64
Iter: 750 Obj: 179050783.7 70
Iter: 800 Obj: 159081206.8 60
Iter: 850 Obj: 156988931.1 66
Iter: 900 Obj: 153866568.9 71
Iter: 950 Obj: 152671686.1 56
Iter: 1000 Obj: 151732794.2 66
Iter: 1050 Obj: 149517085.9 60
Iter: 1100 Obj: 146226975.7 64
Iter: 1150 Obj: 145794484.5 61
Iter: 1200 Obj: 142016510.8 62
Iter: 1250 Obj: 141752858.7 60
Iter: 1300 Obj: 140512977.6 60
Iter: 1350 Obj: 138436586.1 65
Iter: 1400 Obj: 134361523.1 60
Iter: 1450 Obj: 131814854.5 70
Iter: 1500 Obj: 123095681.2 61
Iter: 1550 Obj: 117929795.3 63
Iter: 1600 Obj: 107733768.1 56
Iter: 1650 Obj: 94161350.82 58
Iter: 1700 Obj: 83285014.27 64
Iter: 1750 Obj: 77675254.74 62
Iter: 1800 Obj: 74532566.33 59
Iter: 1850 Obj: 72187323.83 63
Iter: 1900 Obj: 67497619.27 62
Iter: 1950 Obj: 66864529.53 57
Iter: 2000 Obj: 64314421.50 54
Iter: 2050 Obj: 63070672.90 60
Iter: 2100 Obj: 62529793.71 61
Iter: 2150 Obj: 59888476.91 59
Iter: 2200 Obj: 59264475.80 53
Iter: 2250 Obj: 58403961.30 59
Iter: 2300 Obj: 57962258.52 58
Iter: 2350 Obj: 57107897.89 58
Iter: 2400 Obj: 56060805.26 57
Iter: 2450 Obj: 55494454.70 61
```

```
Iter: 2500 Obj: 54744047.33 60
Iter: 2550 Obj: 54498677.35 60
Iter: 2600 Obj: 54207866.76 56
Iter: 2650 Obj: 53714874.53 57
Iter: 2700 Obj: 53105896.27 59
Iter: 2750 Obj: 52860998.18 60
Iter: 2800 Obj: 52544551.61 57
Iter: 2850 Obj: 51866351.56 55
Iter: 2900 Obj: 51698629.62 60
Iter: 2950 Obj: 51564805.14 61
Iter: 3000 Obj: 51182890.25 54
Iter: 3050 Obj: 50779729.23 57
Iter: 3100 Obj: 50058820.75 57
Iter: 3150 Obj: 49954682.29 58
Iter: 3200 Obj: 49558589.04 54
Iter: 3250 Obj: 49390771.95 53
Iter: 3300 Obj: 48664040.37 55
Iter: 3350 Obj: 48385857.01 55
Iter: 3400 Obj: 48196109.12 54
Iter: 3450 Obj: 47934751.58 52
Iter: 3500 Obj: 47617417.77 52
Iter: 3550 Obj: 47278185.84 60
Iter: 3600 Obj: 46979017.75 50
Iter: 3650 Obj: 46861592.46 58
Iter: 3700 Obj: 46376017.06 58
Iter: 3750 Obj: 46253094.41 54
Iter: 3800 Obj: 46123666.43 55
Iter: 3850 Obj: 46047062.90 50
Iter: 3900 Obj: 45996613.74 54
Iter: 3950 Obj: 45919992.61 53
Iter: 4000 Obj: 45532726.02 53
Iter: 4050 Obj: 45323123.17 58
Iter: 4100 Obj: 44953529.01 53
Iter: 4150 Obj: 44825913.67 55
Iter: 4200 Obj: 44732753.44 52
Iter: 4250 Obj: 44614773.07 55
Iter: 4300 Obj: 44501062.45 55
Iter: 4350 Obj: 44003889.83 54
Iter: 4400 Obj: 43807488.49 55
Iter: 4450 Obj: 43390086.60 54
Iter: 4500 Obj: 43149170.67 54
Iter: 4550 Obj: 43047321.98 57
Iter: 4600 Obj: 42927686.18 52
Iter: 4650 Obj: 42883979.59 52
Iter: 4700 Obj: 42857482.64 55
Iter: 4750 Obj: 42769192.04 58
Iter: 4800 Obj: 42724280.32 55
Iter: 4850 Obj: 42688702.14 53
Iter: 4900 Obj: 42668275.65 51
Iter: 4950 Obj: 42594458.26 53
Iter: 5000 Obj: 42354319.49 52
Iter: 5050 Obj: 42289981.03 51
Iter: 5100 Obj: 42254193.65 53
Iter: 5150 Obj: 42157722.91 50
Iter: 5200 Obj: 42120472.80 53
Iter: 5250 Obj: 42079485.02 51
Iter: 5300 Obj: 42068557.38 53
Iter: 5350 Obj: 41958631.24 54
Iter: 5400 Obj: 41929263.87 51
Iter: 5450 Obj: 41913471.85 52
```

```
Iter: 5500 Obj: 41837946.69 51
Iter: 5550 Obj: 41788402.04 50
Iter: 5600 Obj: 41775255.74 51
Iter: 5650 Obj: 41721787.25 51
Iter: 5700 Obj: 41600574.63 53
Iter: 5750 Obj: 41584204.60 52
Iter: 5800 Obj: 41575778.36 51
Iter: 5850 Obj: 41551895.60 54
Iter: 5900 Obj: 41535418.04 51
Iter: 5950 Obj: 41523353.09 50
Iter: 6000 Obj: 41518476.62 51
Iter: 6050 Obj: 41504487.99 50
Iter: 6100 Obj: 41487216.43 53
Iter: 6150 Obj: 41475210.74 53
Iter: 6200 Obj: 41469884.33 52
Iter: 6250 Obj: 41453853.03 52
Iter: 6300 Obj: 41449355.23 50
Iter: 6350 Obj: 41424184.62 51
Iter: 6400 Obj: 41421231.51 50
Iter: 6450 Obj: 41411920.52 51
Iter: 6500 Obj: 41358323.85 41
Iter: 6550 Obj: 41352145.71 18

O P T I M A L   S O L U T I O N ---> OBJECTIVE 41351256.59
SOLVE TIME 00:00:23  ITER 6,593  MEMORY USED   1.4%

--- Restarting execution
--- STORM.GMS(11280)
--- Reading solution for model STORM1
--- STORM.GMS(11281)
--- All done
```

# Appendix D. The data sets of Tonnege and frequency requirement

## TONNAGE REQUIRMENT

| NUMBER | BASE | VALUE | CONTRY | TYPE | AREA | TOTAL |
|---|---|---|---|---|---|---|
| 1 | KCHS.DRRN | 5.53 | usa | TREQ | 1 | 1 |
| 2 | KCHS.EDAF | 3.91 | usa | TREQ | 1 | 2 |
| 3 | KCHS.EGUN | 292.91 | usa | TREQ | 1 | 3 |
| 4 | KCHS.FTTJ | 4.24 | usa | TREQ | 1 | 4 |
| 5 | KCHS.FZAA | 2.55 | usa | TREQ | 1 | 5 |
| 6 | KCHS.GLRB | 0.34 | usa | TREQ | 1 | 6 |
| 7 | KCHS.GOOY | 10.64 | usa | TREQ | 1 | 7 |
| 8 | KCHS.MGGT | 17.36 | usa | TREQ | 1 | 8 |
| 9 | KCHS.MHSC | 216.94 | usa | TREQ | 1 | 9 |
| 10 | KCHS.MHTG | 17.25 | usa | TREQ | 1 | 10 |
| 11 | KCHS.MNMG | 0.22 | usa | TREQ | 1 | 11 |
| 12 | KCHS.MPHO | 493.74 | usa | TREQ | 1 | 12 |
| 13 | KCHS.MSSS | 52.38 | usa | TREQ | 1 | 13 |
| 14 | KCHS.MUGM | 14.82 | usa | TREQ | 1 | 14 |
| 15 | KCHS.SAEZ | 0.1 | usa | TREQ | 1 | 15 |
| 16 | KCHS.SBBR | 26.89 | usa | TREQ | 1 | 16 |
| 17 | KCHS.SBGL | 1.59 | usa | TREQ | 1 | 17 |
| 18 | KCHS.SCEL | 9.18 | usa | TREQ | 1 | 18 |
| 19 | KCHS.SEQU | 14.81 | usa | TREQ | 1 | 19 |
| 20 | KCHS.SGAS | 1.17 | usa | TREQ | 1 | 20 |
| 21 | KCHS.SKBO | 64.34 | usa | TREQ | 1 | 21 |
| 22 | KCHS.SLLP | 37.02 | usa | TREQ | 1 | 22 |
| 23 | KCHS.SPIM | 14.93 | usa | TREQ | 1 | 23 |
| 24 | KCHS.SUMU | 0.32 | usa | TREQ | 1 | 24 |
| 25 | KCHS.SVMI | 9.31 | usa | TREQ | 1 | 25 |
| 26 | KCHS.TAPA | 18.67 | usa | TREQ | 1 | 26 |
| 27 | KCHS.TJNR | 8.68 | usa | TREQ | 1 | 27 |
| 28 | KCOF.FHAW | 77.06 | usa | TREQ | 1 | 28 |
| 29 | KCOF.TAPA | 52.91 | usa | TREQ | 1 | 29 |
| 30 | KDOV.EDAF | 787.57 | usa | TREQ | 1 | 30 |
| 31 | KDOV.EDAR | 744 | usa | TREQ | 1 | 31 |
| 32 | KDOV.EGUN | 6.08 | usa | TREQ | 1 | 32 |
| 33 | KDOV.HECA | 55.52 | usa | TREQ | 1 | 33 |
| 34 | KDOV.LETO | 22.12 | usa | TREQ | 1 | 34 |
| 35 | KDOV.LGIR | 9.07 | usa | TREQ | 1 | 35 |
| 36 | KDOV.LIPA | 173.77 | usa | TREQ | 1 | 36 |
| 37 | KDOV.LLBG | 5.65 | usa | TREQ | 1 | 37 |
| 38 | KDOV.LTAG | 140.19 | usa | TREQ | 1 | 38 |
| 39 | KDOV.OEDR | 323.47 | usa | TREQ | 1 | 39 |
| 40 | KDOV.OERY | 199.12 | usa | TREQ | 1 | 40 |
| 41 | KDOV.OJAF | 8.64 | usa | TREQ | 1 | 41 |
| 42 | KDOV.RODN | 8.87 | usa | TREQ | 1 | 42 |
| 43 | KNGU.BIKF | 142.76 | usa | TREQ | 1 | 43 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 44 | KNGU.HKNA | 3.7 | usa | TREQ | 1 | 44 |
| 45 | KNGU.LERT | 132.13 | usa | TREQ | 1 | 45 |
| 46 | KNGU.LICZ | 105.19 | usa | TREQ | 1 | 46 |
| 47 | KNGU.LIPA | 21.26 | usa | TREQ | 1 | 47 |
| 48 | KNGU.LIRN | 64.63 | usa | TREQ | 1 | 48 |
| 49 | KNGU.MUGM | 271.3 | usa | TREQ | 1 | 49 |
| 50 | KNGU.OBBI | 63.69 | usa | TREQ | 1 | 50 |
| 51 | KNGU.OMFJ | 40.88 | usa | TREQ | 1 | 51 |
| 52 | KNGU.TISX | 29.87 | usa | TREQ | 1 | 52 |
| 53 | KNGU.TJNR | 211.93 | usa | TREQ | 1 | 53 |
| 54 | KNGU.TXKF | 128.44 | usa | TREQ | 1 | 54 |
| 55 | KSUU.ABAS | 106.86 | usa | TREQ | 1 | 55 |
| 56 | KSUU.APLM | 25.32 | usa | TREQ | 1 | 56 |
| 57 | KSUU.APWR | 11.04 | usa | TREQ | 1 | 57 |
| 58 | KSUU.ASRI | 34.67 | usa | TREQ | 1 | 58 |
| 59 | KSUU.FJDG | 40.33 | usa | TREQ | 1 | 59 |
| 60 | KSUU.NSTU | 1.1 | usa | TREQ | 1 | 60 |
| 61 | KSUU.NZCH | 22.55 | usa | TREQ | 1 | 61 |
| 62 | KSUU.OBBI | 0.04 | usa | TREQ | 1 | 62 |
| 63 | KSUU.OEDR | 0.02 | usa | TREQ | 1 | 63 |
| 64 | KSUU.PAED | 239.52 | usa | TREQ | 1 | 64 |
| 65 | KSUU.PGUA | 196.14 | usa | TREQ | 1 | 65 |
| 66 | KSUU.PHIK | 545.56 | usa | TREQ | 1 | 66 |
| 67 | KSUU.PJON | 11.91 | usa | TREQ | 1 | 67 |
| 68 | KSUU.PKWA | 70.41 | usa | TREQ | 1 | 68 |
| 69 | KSUU.PWAK | 1.87 | usa | TREQ | 1 | 69 |
| 70 | KSUU.RJFF | 16.32 | usa | TREQ | 1 | 70 |
| 71 | KSUU.RJOI | 25.02 | usa | TREQ | 1 | 71 |
| 72 | KSUU.RJSM | 108.69 | usa | TREQ | 1 | 72 |
| 73 | KSUU.RJTY | 340.32 | usa | TREQ | 1 | 73 |
| 74 | KSUU.RKJK | 32.71 | usa | TREQ | 1 | 74 |
| 75 | KSUU.RKPK | 20.47 | usa | TREQ | 1 | 75 |
| 76 | KSUU.RKSO | 634.2 | usa | TREQ | 1 | 76 |
| 77 | KSUU.RODN | 392.99 | usa | TREQ | 1 | 77 |
| 78 | KSUU.VTBD | 9.09 | usa | TREQ | 1 | 78 |
| 79 | KSUU.WIIH | 5.06 | usa | TREQ | 1 | 79 |
| 80 | KSUU.WSAP | 18.68 | usa | TREQ | 1 | 80 |
| 81 | KTCM.PADK | 81.12 | usa | TREQ | 1 | 81 |
| 82 | KTCM.PAED | 62.5 | usa | TREQ | 1 | 82 |
| 83 | KTCM.PHIK | 6.39 | usa | TREQ | 1 | 83 |
| 84 | KTCM.RJTY | 0.12 | usa | TREQ | 1 | 84 |
| 85 | KTCM.RODN | 10.71 | usa | TREQ | 1 | 85 |
| 86 | KWRI.BGTL | 146.24 | usa | TREQ | 1 | 86 |
| 87 | KWRI.EDAR | 1.4 | usa | TREQ | 1 | 87 |
| 88 | KWRI.LPLA | 285.47 | usa | TREQ | 1 | 88 |
| 89 | PADK.KSUU | 29.37 | alaska | TREQ | 1 | 89 |
| 90 | PADK.KTCM | 9.96 | alaska | TREQ | 1 | 90 |
| 91 | PADK.PAED | 2.33 | alaska | TREQ | 1 | 91 |
| 92 | PADK.PHIK | 1.92 | alaska | TREQ | 1 | 92 |
| 93 | PAED.KSUU | 330.32 | alaska | TREQ | 1 | 93 |
| 94 | PAED.KTCM | 14.41 | alaska | TREQ | 1 | 94 |

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|---|---|---|---|---|---|---|
| 95 | PAED.PADK | 10.15 | alaska | TREQ | 1 | 95 |
| 96 | PAED.PHIK | 4.6 | alaska | TREQ | 1 | 96 |
| 97 | PAED.RJTY | 18.74 | alaska | TREQ | 1 | 97 |
| 98 | PAED.RKSO | 25.54 | alaska | TREQ | 1 | 98 |
| 99 | PAED.RODN | 7.99 | alaska | TREQ | 1 | 99 |
| 100 | PAHT.PAED | 4.53 | alaska | TREQ | 1 | 100 |
| 101 | PGUA.KSUU | 83.91 | mariana island | TREQ | 1 | 101 |
| 102 | PGUA.PHIK | 4.93 | mariana island | TREQ | 1 | 102 |
| 103 | PGUA.RJSM | 0.01 | mariana island | TREQ | 1 | 103 |
| 104 | PGUA.RJTY | 2.83 | mariana island | TREQ | 1 | 104 |
| 105 | PGUA.RKSO | 9.66 | mariana island | TREQ | 1 | 105 |
| 106 | PGUA.RODN | 9.89 | mariana island | TREQ | 1 | 106 |
| 107 | PJON.KSUU | 18.63 | johnston island | TREQ | 1 | 107 |
| 108 | PJON.PHIK | 30.43 | johnston island | TREQ | 1 | 108 |
| 109 | PKWA.KSUU | 27.65 | mashall island | TREQ | 1 | 109 |
| 110 | PKWA.PHIK | 73.3 | mashall island | TREQ | 1 | 110 |
| 111 | PMDY.PHIK | 4.49 | line island | TREQ | 1 | 111 |
| 112 | PWAK.KSUU | 6.53 | wake island | TREQ | 1 | 112 |
| 113 | PWAK.PHIK | 0.39 | wake island | TREQ | 1 | 113 |
| 1 | MGGT.MPHO | 0.02 | guatemala | TREQ | 2 | 114 |
| 2 | MHSC.KCHS | 83.21 | honduras | TREQ | 2 | 115 |
| 3 | MHSC.MPHO | 29.94 | honduras | TREQ | 2 | 116 |
| 4 | MHTG.KCHS | 6.68 | honduras | TREQ | 2 | 117 |
| 5 | MHTG.MPHO | 0.13 | honduras | TREQ | 2 | 118 |
| 6 | MKJP.MUGM | 6.21 | jamaica | TREQ | 2 | 119 |
| 7 | MPHO.KCHS | 356.59 | panama | TREQ | 2 | 120 |
| 8 | MPHO.MGGT | 8.39 | panama | TREQ | 2 | 121 |
| 9 | MPHO.MHSC | 109.61 | panama | TREQ | 2 | 122 |
| 10 | MPHO.MHTG | 19.69 | panama | TREQ | 2 | 123 |
| 11 | MPHO.MNMG | 14.06 | panama | TREQ | 2 | 124 |
| 12 | MPHO.MROC | 3.2 | panama | TREQ | 2 | 125 |
| 13 | MPHO.MSSS | 23.18 | panama | TREQ | 2 | 126 |
| 14 | MPHO.MZBZ | 9.79 | panama | TREQ | 2 | 127 |
| 15 | MPHO.SAEZ | 4.59 | panama | TREQ | 2 | 128 |
| 16 | MPHO.SBBR | 6.22 | panama | TREQ | 2 | 129 |
| 17 | MPHO.SBGL | 0.74 | panama | TREQ | 2 | 130 |
| 18 | MPHO.SCEL | 0.65 | panama | TREQ | 2 | 131 |
| 19 | MPHO.SEQU | 12.63 | panama | TREQ | 2 | 132 |
| 20 | MPHO.SGAS | 1.4 | panama | TREQ | 2 | 133 |
| 21 | MPHO.SKBO | 9.42 | panama | TREQ | 2 | 134 |
| 22 | MPHO.SLLP | 14.02 | panama | TREQ | 2 | 135 |
| 23 | MPHO.SPIM | 12.9 | panama | TREQ | 2 | 136 |
| 24 | MPHO.SUMU | 0.03 | panama | TREQ | 2 | 137 |
| 25 | MPHO.SVMI | 0.71 | panama | TREQ | 2 | 138 |
| 26 | MROC.MPHO | 3 | costa rica | TREQ | 2 | 139 |
| 27 | MSSS.KCHS | 27.5 | el salvador | TREQ | 2 | 140 |
| 28 | MSSS.MPHO | 0.01 | el salvador | TREQ | 2 | 141 |
| 29 | MUGM.KNGU | 34.81 | cuba | TREQ | 2 | 142 |
| 30 | SAEZ.MPHO | 0.04 | argentina | TREQ | 2 | 143 |
| 31 | SBBR.KCHS | 7.13 | brazil | TREQ | 2 | 144 |
| 32 | SBGL.KCHS | 6.94 | brazil | TREQ | 2 | 145 |

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|---|---|---|---|---|---|
| 33 | SBGL.MPHO | 7.01 | brazil | TREQ | 2 | 146 |
| 34 | SCEL.KCHS | 11.92 | chile | TREQ | 2 | 147 |
| 35 | SEQU.MPHO | 0.5 | ecuador | TREQ | 2 | 148 |
| 36 | SGAS.KCHS | 7.16 | paraguay | TREQ | 2 | 149 |
| 37 | SGAS.MPHO | 0.16 | paraguay | TREQ | 2 | 150 |
| 38 | SKBO.KCHS | 12.01 | colombia | TREQ | 2 | 151 |
| 39 | SKBO.MPHO | 0.35 | colombia | TREQ | 2 | 152 |
| 40 | SLLP.KCHS | 0.39 | bolivia | TREQ | 2 | 153 |
| 41 | SLLP.MPHO | 0.89 | bolivia | TREQ | 2 | 154 |
| 42 | SPIM.KCHS | 3.67 | peru | TREQ | 2 | 155 |
| 43 | SPIM.MPHO | 0.6 | peru | TREQ | 2 | 156 |
| 44 | SUMU.MPHO | 0.09 | uruguay | TREQ | 2 | 157 |
| 45 | SVMI.KCHS | 5.55 | venezuela | TREQ | 2 | 158 |
| 46 | SVMI.MPHO | 0.23 | venezuela | TREQ | 2 | 159 |
| 47 | TAPA.KCOF | 6.53 | antigua and barbuda | TREQ | 2 | 160 |
| 48 | TJNR.KCHS | 36.62 | pueto rico | TREQ | 2 | 161 |
| 49 | TJNR.KNGU | 42.64 | pueto rico | TREQ | 2 | 162 |
| 50 | TJNR.MUGM | 0.24 | pueto rico | TREQ | 2 | 163 |
| 51 | TJNR.TAPA | 1.07 | pueto rico | TREQ | 2 | 164 |
| 52 | TJNR.TBPB | 8.54 | pueto rico | TREQ | 2 | 165 |
| 53 | TXKF.KNGU | 28.11 | bermuda | TREQ | 2 | 166 |
| 1 | BGTL.KWRI | 156.18 | greenland(denmark) | TREQ | 3 | 167 |
| 2 | BIKF.KNGU | 2.86 | iceland | TREQ | 3 | 168 |
| 3 | EDAF.EDAR | 4.64 | germany | TREQ | 3 | 169 |
| 4 | EDAF.EGUN | 81.32 | germany | TREQ | 3 | 170 |
| 5 | EDAF.KDOV | 923.74 | germany | TREQ | 3 | 171 |
| 6 | EDAF.LETO | 5.97 | germany | TREQ | 3 | 172 |
| 7 | EDAF.LGIR | 10.46 | germany | TREQ | 3 | 173 |
| 8 | EDAF.LICZ | 8.16 | germany | TREQ | 3 | 174 |
| 9 | EDAF.LIPA | 69.31 | germany | TREQ | 3 | 175 |
| 10 | EDAF.LIRN | 1.84 | germany | TREQ | 3 | 176 |
| 11 | EDAF.LLBG | 11.01 | germany | TREQ | 3 | 177 |
| 12 | EDAF.LTAG | 211.83 | germany | TREQ | 3 | 178 |
| 13 | EDAF.OEDR | 162.35 | germany | TREQ | 3 | 179 |
| 14 | EDAF.OERY | 100.03 | germany | TREQ | 3 | 180 |
| 15 | EDAF.OJAF | 5 | germany | TREQ | 3 | 181 |
| 16 | EDAR.EDAF | 4.86 | germany | TREQ | 3 | 182 |
| 17 | EDAR.EGUN | 58.06 | germany | TREQ | 3 | 183 |
| 18 | EDAR.HECA | 21.67 | germany | TREQ | 3 | 184 |
| 19 | EDAR.KDOV | 947.49 | germany | TREQ | 3 | 185 |
| 20 | EDAR.KNGU | 23.6 | germany | TREQ | 3 | 186 |
| 21 | EDAR.KWRI | 9.6 | germany | TREQ | 3 | 187 |
| 22 | EDAR.LETO | 7.4 | germany | TREQ | 3 | 188 |
| 23 | EDAR.LGIR | 1.34 | germany | TREQ | 3 | 189 |
| 24 | EDAR.LICZ | 16.59 | germany | TREQ | 3 | 190 |
| 25 | EDAR.LIPA | 51.65 | germany | TREQ | 3 | 191 |
| 26 | EDAR.LIRN | 6.83 | germany | TREQ | 3 | 192 |
| 27 | EDAR.LPLA | 20.44 | germany | TREQ | 3 | 193 |
| 28 | EDAR.LTAG | 17.96 | germany | TREQ | 3 | 194 |
| 29 | EDAR.OEDR | 14.08 | germany | TREQ | 3 | 195 |
| 30 | EDAR.OJAF | 19.14 | germany | TREQ | 3 | 196 |

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|---|---|---|---|---|---|
| 31 | EGUN.EDAF | 18.93 | united kindom | TREQ | 3 | 197 |
| 32 | EGUN.EDAR | 27.97 | united kindom | TREQ | 3 | 198 |
| 33 | EGUN.KCHS | 345.78 | united kindom | TREQ | 3 | 199 |
| 34 | EGUN.KDOV | 35.71 | united kindom | TREQ | 3 | 200 |
| 35 | EGUN.KNGU | 0.19 | united kindom | TREQ | 3 | 201 |
| 36 | EGUN.LETO | 3.74 | united kindom | TREQ | 3 | 202 |
| 37 | EGUN.LICZ | 5.85 | united kindom | TREQ | 3 | 203 |
| 38 | EGUN.LIPA | 4.84 | united kindom | TREQ | 3 | 204 |
| 39 | EGUN.LPLA | 0.09 | united kindom | TREQ | 3 | 205 |
| 40 | EGUN.LTAG | 18.42 | united kindom | TREQ | 3 | 206 |
| 41 | FHAW.KCOF | 18.09 | ascension island | TREQ | 3 | 207 |
| 42 | FJDG.KSUU | 95.26 | british indian ocean territory | TREQ | 3 | 208 |
| 43 | FJDG.OMFJ | 15.76 | british indian ocean territory | TREQ | 3 | 209 |
| 44 | FJDG.RJTY | 27.14 | british indian ocean territory | TREQ | 3 | 210 |
| 45 | FJDG.RODN | 0.47 | british indian ocean territory | TREQ | 3 | 211 |
| 46 | FJDG.WSAP | 17.1 | british indian ocean territory | TREQ | 3 | 212 |
| 47 | HECA.EDAR | 5.62 | egypt | TREQ | 3 | 213 |
| 48 | HECA.KDOV | 16.39 | egypt | TREQ | 3 | 214 |
| 49 | LERT.KNGU | 138.37 | espania | TREQ | 3 | 215 |
| 50 | LERT.LICZ | 12.32 | espania | TREQ | 3 | 216 |
| 51 | LERT.LIRN | 8.19 | espania | TREQ | 3 | 217 |
| 52 | LERT.LPLA | 0.42 | espania | TREQ | 3 | 218 |
| 53 | LERT.LTAG | 5.51 | espania | TREQ | 3 | 219 |
| 54 | LERT.OBBI | 4.52 | espania | TREQ | 3 | 220 |
| 55 | LETO.EDAF | 10.02 | espania | TREQ | 3 | 221 |
| 56 | LETO.EDAR | 2.31 | espania | TREQ | 3 | 222 |
| 57 | LETO.EGUN | 0.88 | espania | TREQ | 3 | 223 |
| 58 | LETO.KDOV | 58.26 | espania | TREQ | 3 | 224 |
| 59 | LETO.LERT | 5.6 | espania | TREQ | 3 | 225 |
| 60 | LETO.LGIR | 1.99 | espania | TREQ | 3 | 226 |
| 61 | LETO.LICZ | 1.95 | espania | TREQ | 3 | 227 |
| 62 | LETO.LIPA | 16.57 | espania | TREQ | 3 | 228 |
| 63 | LETO.LIRN | 3.09 | espania | TREQ | 3 | 229 |
| 64 | LETO.LLBG | 9.9 | espania | TREQ | 3 | 230 |
| 65 | LETO.LTAG | 2.71 | espania | TREQ | 3 | 231 |
| 66 | LETO.OBBI | 0.23 | espania | TREQ | 3 | 232 |
| 67 | LGIR.KDOV | 19.61 | greece | TREQ | 3 | 233 |
| 68 | LGIR.LIPA | 7.53 | greece | TREQ | 3 | 234 |
| 69 | LICZ.EDAF | 4.03 | italie | TREQ | 3 | 235 |
| 70 | LICZ.KDOV | 9.81 | italie | TREQ | 3 | 236 |
| 71 | LICZ.KNGU | 143.87 | italie | TREQ | 3 | 237 |
| 72 | LICZ.LERT | 11.36 | italie | TREQ | 3 | 238 |
| 73 | LICZ.LETO | 0.07 | italie | TREQ | 3 | 239 |
| 74 | LICZ.LIPA | 11.99 | italie | TREQ | 3 | 240 |
| 75 | LICZ.LIRN | 18.47 | italie | TREQ | 3 | 241 |
| 76 | LICZ.LTAG | 4.82 | italie | TREQ | 3 | 242 |
| 77 | LICZ.OBBI | 11.51 | italie | TREQ | 3 | 243 |
| 78 | LICZ.OEDR | 1.98 | italie | TREQ | 3 | 244 |
| 79 | LICZ.OMFJ | 1.22 | italie | TREQ | 3 | 245 |
| 80 | LIPA.EDAF | 0.03 | italie | TREQ | 3 | 246 |
| 81 | LIPA.EDAR | 0.05 | italie | TREQ | 3 | 247 |

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|---|---|---|---|---|---|
| 82 | LIPA.EGUN | 0.55 | italie | TREQ | 3 | 248 |
| 83 | LIPA.KDOV | 3.41 | italie | TREQ | 3 | 249 |
| 84 | LIPA.LETO | 0.02 | italie | TREQ | 3 | 250 |
| 85 | LIPA.LIRN | 4.09 | italie | TREQ | 3 | 251 |
| 86 | LLBG.KDOV | 10.28 | israel | TREQ | 3 | 252 |
| 87 | LPLA.KWRI | 99.07 | portugal | TREQ | 3 | 253 |
| 88 | LTAG.EDAF | 60.28 | turkey | TREQ | 3 | 254 |
| 89 | LTAG.EDAR | 101.43 | turkey | TREQ | 3 | 255 |
| 90 | LTAG.EGUN | 71.51 | turkey | TREQ | 3 | 256 |
| 91 | LTAG.KDOV | 176.99 | turkey | TREQ | 3 | 257 |
| 92 | LTAG.LETO | 2.13 | turkey | TREQ | 3 | 258 |
| 93 | LTAG.LGIR | 4.02 | turkey | TREQ | 3 | 259 |
| 94 | LTAG.LIPA | 7.65 | turkey | TREQ | 3 | 260 |
| 95 | LTAG.LIRN | 6.23 | turkey | TREQ | 3 | 261 |
| 96 | LTAG.LLBG | 1.31 | turkey | TREQ | 3 | 262 |
| 97 | OBBI.KNGU | 110.03 | bahrain | TREQ | 3 | 263 |
| 98 | OBBI.LICZ | 9.34 | bahrain | TREQ | 3 | 264 |
| 99 | OEDR.EDAF | 15.09 | saudi arabia | TREQ | 3 | 265 |
| 100 | OEDR.KDOV | 106.79 | saudi arabia | TREQ | 3 | 266 |
| 101 | OJAF.EDAR | 6.34 | jordan | TREQ | 3 | 267 |
| 102 | OJAF.KDOV | 5.19 | jordan | TREQ | 3 | 268 |
| 1 | RJAM.RJTY | 1 | japan | TREQ | 4 | 269 |
| 2 | RJAW.RJTY | 11.86 | japan | TREQ | 4 | 270 |
| 3 | RJCB.RJTY | 1.77 | japan | TREQ | 4 | 271 |
| 4 | RJFF.KSUU | 6.41 | japan | TREQ | 4 | 272 |
| 5 | RJFF.RJTY | 0.07 | japan | TREQ | 4 | 273 |
| 6 | RJOI.KSUU | 14.3 | japan | TREQ | 4 | 274 |
| 7 | RJOI.RJTY | 6.99 | japan | TREQ | 4 | 275 |
| 8 | RJOI.RODN | 26.18 | japan | TREQ | 4 | 276 |
| 9 | RJSM.KSUU | 57.58 | japan | TREQ | 4 | 277 |
| 10 | RJSM.PHIK | 0.19 | japan | TREQ | 4 | 278 |
| 11 | RJSM.RJTY | 52.2 | japan | TREQ | 4 | 279 |
| 12 | RJSM.RKJK | 0.03 | japan | TREQ | 4 | 280 |
| 13 | RJSM.RODN | 2.1 | japan | TREQ | 4 | 281 |
| 14 | RJTY.EDAF | 0.28 | japan | TREQ | 4 | 282 |
| 15 | RJTY.FJDG | 162.67 | japan | TREQ | 4 | 283 |
| 16 | RJTY.KSUU | 338.31 | japan | TREQ | 4 | 284 |
| 17 | RJTY.KTCM | 31.05 | japan | TREQ | 4 | 285 |
| 18 | RJTY.OMFJ | 45.88 | japan | TREQ | 4 | 286 |
| 19 | RJTY.PAED | 16.6 | japan | TREQ | 4 | 287 |
| 20 | RJTY.PGUA | 25.51 | japan | TREQ | 4 | 288 |
| 21 | RJTY.PHIK | 13.83 | japan | TREQ | 4 | 289 |
| 22 | RJTY.PWAK | 4.05 | japan | TREQ | 4 | 290 |
| 23 | RJTY.RJAM | 2.68 | japan | TREQ | 4 | 291 |
| 24 | RJTY.RJAW | 8.71 | japan | TREQ | 4 | 292 |
| 25 | RJTY.RJCB | 1.66 | japan | TREQ | 4 | 293 |
| 26 | RJTY.RJFF | 13.58 | japan | TREQ | 4 | 294 |
| 27 | RJTY.RJOI | 27.51 | japan | TREQ | 4 | 295 |
| 28 | RJTY.RJSM | 159.37 | japan | TREQ | 4 | 296 |
| 29 | RJTY.RKJK | 0.49 | japan | TREQ | 4 | 297 |
| 30 | RJTY.RKPK | 0.16 | japan | TREQ | 4 | 298 |

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| 31 | RJTY.RKSO | 50.9 | japan | TREQ | 4 | 299 |
| 32 | RJTY.RKTN | 0.18 | japan | TREQ | 4 | 300 |
| 33 | RJTY.RODN | 69.03 | japan | TREQ | 4 | 301 |
| 34 | RJTY.VTBD | 2.57 | japan | TREQ | 4 | 302 |
| 35 | RJTY.WSAP | 28.43 | japan | TREQ | 4 | 303 |
| 36 | RKJK.KSUU | 25.67 | korea | TREQ | 4 | 304 |
| 37 | RKJK.RJTY | 1.8 | korea | TREQ | 4 | 305 |
| 38 | RKJK.RKSO | 3.81 | korea | TREQ | 4 | 306 |
| 39 | RKJK.RODN | 8.22 | korea | TREQ | 4 | 307 |
| 40 | RKSO.KSUU | 647.15 | korea | TREQ | 4 | 308 |
| 41 | RKSO.KTCM | 14.96 | korea | TREQ | 4 | 309 |
| 42 | RKSO.PHIK | 4.19 | korea | TREQ | 4 | 310 |
| 43 | RKSO.RJTY | 28.92 | korea | TREQ | 4 | 311 |
| 44 | RKSO.RKJK | 10.88 | korea | TREQ | 4 | 312 |
| 45 | RKSO.RKPK | 12.8 | korea | TREQ | 4 | 313 |
| 46 | RKSO.RODN | 25.7 | korea | TREQ | 4 | 314 |
| 47 | RODN.FJDG | 2.67 | japan | TREQ | 4 | 315 |
| 48 | RODN.KSUU | 254.33 | japan | TREQ | 4 | 316 |
| 49 | RODN.PAED | 6.68 | japan | TREQ | 4 | 317 |
| 50 | RODN.PGUA | 20.17 | japan | TREQ | 4 | 318 |
| 51 | RODN.PHIK | 25.37 | japan | TREQ | 4 | 319 |
| 52 | RODN.RJOI | 30.77 | japan | TREQ | 4 | 320 |
| 53 | RODN.RJSM | 3.68 | japan | TREQ | 4 | 321 |
| 54 | RODN.RJTY | 87.59 | japan | TREQ | 4 | 322 |
| 55 | RODN.RKJK | 3.69 | japan | TREQ | 4 | 323 |
| 56 | RODN.RKPK | 2.91 | japan | TREQ | 4 | 324 |
| 57 | RODN.RKSO | 41.46 | japan | TREQ | 4 | 325 |
| 58 | RODN.VTBD | 17.53 | japan | TREQ | 4 | 326 |
| 59 | RODN.WIIH | 1.96 | japan | TREQ | 4 | 327 |
| 60 | RODN.WSAP | 10.55 | japan | TREQ | 4 | 328 |
| 1 | ABAS.KSUU | 18.58 | solomom islands | TREQ | 5 | 329 |
| 2 | APLM.KSUU | 31.68 | solomom islands | TREQ | 5 | 330 |
| 3 | APLM.PGUA | 5.74 | solomom islands | TREQ | 5 | 331 |
| 4 | APLM.PHIK | 0.35 | solomom islands | TREQ | 5 | 332 |
| 5 | APWR.KSUU | 17.24 | solomom islands | TREQ | 5 | 333 |
| 6 | ASRI.ABAS | 2.7 | papua new guinea | TREQ | 5 | 334 |
| 7 | ASRI.APLM | 2.57 | papua new guinea | TREQ | 5 | 335 |
| 8 | ASRI.APWR | 6.88 | papua new guinea | TREQ | 5 | 336 |
| 9 | ASRI.KSUU | 50.51 | papua new guinea | TREQ | 5 | 337 |
| 10 | ASRI.PHIK | 5.01 | papua new guinea | TREQ | 5 | 338 |
| 11 | NSTU.PHIK | 0.4 | samoa | TREQ | 5 | 339 |
| 12 | NZCH.KSUU | 20.14 | new zealand | TREQ | 5 | 340 |
| 13 | PHIK.ASRI | 13.12 | hawaii | TREQ | 5 | 341 |
| 14 | PHIK.FJDG | 9.79 | hawaii | TREQ | 5 | 342 |
| 15 | PHIK.KSUU | 451.39 | hawaii | TREQ | 5 | 343 |
| 16 | PHIK.KTCM | 51.49 | hawaii | TREQ | 5 | 344 |
| 17 | PHIK.NSTU | 1.84 | hawaii | TREQ | 5 | 345 |
| 18 | PHIK.PAED | 2.95 | hawaii | TREQ | 5 | 346 |
| 19 | PHIK.PGUA | 17.56 | hawaii | TREQ | 5 | 347 |
| 20 | PHIK.PJON | 163.57 | hawaii | TREQ | 5 | 348 |
| 21 | PHIK.PKWA | 122.46 | hawaii | TREQ | 5 | 349 |

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|---|---|---|---|---|---|
| 22 | PHIK.PMDY | 11.82 | hawaii | TREQ | 5 | 350 |
| 23 | PHIK.PWAK | 70.38 | hawaii | TREQ | 5 | 351 |
| 24 | PHIK.RJTY | 7.57 | hawaii | TREQ | 5 | 352 |
| 25 | PHIK.RKSO | 3.02 | hawaii | TREQ | 5 | 353 |
| 26 | PHIK.RODN | 17.69 | hawaii | TREQ | 5 | 354 |
| 27 | VTBD.RODN | 2.76 | thailand | TREQ | 5 | 355 |
| 28 | WIIH.KSUU | 4.33 | indonesia | TREQ | 5 | 356 |
| 29 | WIIH.RODN | 0.01 | indonesia | TREQ | 5 | 357 |
| 30 | WSAP.FJDG | 12.69 | singapore | TREQ | 5 | 358 |
| 31 | WSAP.KSUU | 6.92 | singapore | TREQ | 5 | 359 |
| 32 | WSAP.RJTY | 2.31 | singapore | TREQ | 5 | 360 |

## FREQUENCY REQUIRMENT

| NUMBER | BASE | VALUE | CONTRY | TYPE | AREA | TOTAL |
|---|---|---|---|---|---|---|
| 1 | CYYT.KWRI | 2 | canada | FREQ | 1 | 1 |
| 2 | KCHS.FTTJ | 1 | usa | FREQ | 1 | 2 |
| 3 | KCHS.FZAA | 2 | usa | FREQ | 1 | 3 |
| 4 | KCHS.GLRB | 2 | usa | FREQ | 1 | 4 |
| 5 | KCHS.MHSC | 4 | usa | FREQ | 1 | 5 |
| 6 | KCHS.MPHO | 4 | usa | FREQ | 1 | 6 |
| 7 | KCHS.SAEZ | 2 | usa | FREQ | 1 | 7 |
| 8 | KCHS.SBGL | 2 | usa | FREQ | 1 | 8 |
| 9 | KCHS.SCEL | 2 | usa | FREQ | 1 | 9 |
| 10 | KCHS.SGAS | 2 | usa | FREQ | 1 | 10 |
| 11 | KCHS.SLLP | 2 | usa | FREQ | 1 | 11 |
| 12 | KCHS.SUMU | 2 | usa | FREQ | 1 | 12 |
| 13 | KDOV.OJAF | 2 | usa | FREQ | 1 | 13 |
| 14 | KNGU.LICZ | 15 | usa | FREQ | 1 | 14 |
| 15 | KNGU.LIRN | 12 | usa | FREQ | 1 | 15 |
| 16 | KNGU.MUGM | 12 | usa | FREQ | 1 | 16 |
| 17 | KNGU.OBBI | 12 | usa | FREQ | 1 | 17 |
| 18 | KNGU.OMFJ | 15 | usa | FREQ | 1 | 18 |
| 19 | KNGU.TJNR | 4 | usa | FREQ | 1 | 19 |
| 20 | KNGU.TXKF | 3 | usa | FREQ | 1 | 20 |
| 21 | KSUU.PGUA | 4 | usa | FREQ | 1 | 21 |
| 22 | KTCM.PADK | 4 | usa | FREQ | 1 | 22 |
| 23 | KWRI.BGTL | 4 | usa | FREQ | 1 | 23 |
| 24 | KWRI.CYYT | 2 | usa | FREQ | 1 | 24 |
| 25 | KWRI.LPLA | 13 | usa | FREQ | 1 | 25 |
| 26 | PADK.KTCM | 4 | alaska | FREQ | 1 | 26 |
| 27 | PGUA.KSUU | 4 | mariana island | FREQ | 1 | 27 |
| 28 | PGUA.RODN | 8 | mariana island | FREQ | 1 | 28 |
| 29 | PJON.PHIK | 8 | johnston island | FREQ | 1 | 29 |
| 30 | PKWA.PHIK | 8 | mashall island | FREQ | 1 | 30 |
| 31 | PMDY.PHIK | 4 | line island | FREQ | 1 | 31 |
| 32 | PWAK.PHIK | 6 | wake island | FREQ | 1 | 32 |
| 1 | MGGT.MPHO | 2 | guatemala | FREQ | 2 | 33 |
| 2 | MHSC.KCHS | 4 | honduras | FREQ | 2 | 34 |
| 3 | MHSC.MPHO | 8 | honduras | FREQ | 2 | 35 |
| 4 | MHTG.MPHO | 8 | honduras | FREQ | 2 | 36 |
| 5 | MNMG.MPHO | 2 | nicaragua | FREQ | 2 | 37 |
| 6 | MPHO.KCHS | 4 | panama | FREQ | 2 | 38 |
| 7 | MPHO.MGGT | 2 | panama | FREQ | 2 | 39 |
| 8 | MPHO.MHSC | 8 | panama | FREQ | 2 | 40 |
| 9 | MPHO.MHTG | 8 | panama | FREQ | 2 | 41 |
| 10 | MPHO.MNMG | 2 | panama | FREQ | 2 | 42 |
| 11 | MPHO.MROC | 2 | panama | FREQ | 2 | 43 |
| 12 | MPHO.MSSS | 8 | panama | FREQ | 2 | 44 |
| 13 | MPHO.SAEZ | 2 | panama | FREQ | 2 | 45 |

| | | | | | |
|---|---|---|---|---|---|
| 14 | MPHO.SBBR | 2 panama | FREQ | 2 | 46 |
| 15 | MPHO.SBGL | 2 panama | FREQ | 2 | 47 |
| 16 | MPHO.SCEL | 2 panama | FREQ | 2 | 48 |
| 17 | MPHO.SEQU | 1 panama | FREQ | 2 | 49 |
| 18 | MPHO.SGAS | 2 panama | FREQ | 2 | 50 |
| 19 | MPHO.SKBO | 1 panama | FREQ | 2 | 51 |
| 20 | MPHO.SLLP | 2 panama | FREQ | 2 | 52 |
| 21 | MPHO.SPIM | 2 panama | FREQ | 2 | 53 |
| 22 | MPHO.SUMU | 2 panama | FREQ | 2 | 54 |
| 23 | MPHO.SVMI | 1 panama | FREQ | 2 | 55 |
| 24 | MROC.MPHO | 2 costa rica | FREQ | 2 | 56 |
| 25 | MSSS.MPHO | 8 el salvador | FREQ | 2 | 57 |
| 26 | MUGM.KNGU | 12 cuba | FREQ | 2 | 58 |
| 27 | SAEZ.KCHS | 2 argentina | FREQ | 2 | 59 |
| 28 | SAEZ.MPHO | 2 argentina | FREQ | 2 | 60 |
| 29 | SBGL.KCHS | 2 brazil | FREQ | 2 | 61 |
| 30 | SBGL.MPHO | 2 brazil | FREQ | 2 | 62 |
| 31 | SCEL.KCHS | 2 chile | FREQ | 2 | 63 |
| 32 | SCEL.MPHO | 2 chile | FREQ | 2 | 64 |
| 33 | SEQU.MPHO | 1 ecuador | FREQ | 2 | 65 |
| 34 | SGAS.MPHO | 2 paraguay | FREQ | 2 | 66 |
| 35 | SKBO.MPHO | 1 colombia | FREQ | 2 | 67 |
| 36 | SLLP.KCHS | 2 bolivia | FREQ | 2 | 68 |
| 37 | SLLP.MPHO | 2 bolivia | FREQ | 2 | 69 |
| 38 | SPIM.MPHO | 2 peru | FREQ | 2 | 70 |
| 39 | SUMU.KCHS | 2 uruguay | FREQ | 2 | 71 |
| 40 | SUMU.MPHO | 2 uruguay | FREQ | 2 | 72 |
| 41 | SVMI.MPHO | 1 venezuela | FREQ | 2 | 73 |
| 42 | TAPA.TJNR | 2 antigua and barbuda | FREQ | 2 | 74 |
| 43 | TISX.TJNR | 4 virgin island | FREQ | 2 | 75 |
| 44 | TJNR.KNGU | 4 pueto rico | FREQ | 2 | 76 |
| 45 | TJNR.MTPP | 1 pueto rico | FREQ | 2 | 77 |
| 46 | TJNR.TAPA | 2 pueto rico | FREQ | 2 | 78 |
| 47 | TJNR.TISX | 4 pueto rico | FREQ | 2 | 79 |
| 48 | TXKF.KNGU | 3 bermuda | FREQ | 2 | 80 |
| 1 | BGTL.KWRI | 4 greenland(denmark) | FREQ | 3 | 81 |
| 2 | EDAF.LETO | 4 germany | FREQ | 3 | 82 |
| 3 | EDAF.LTAG | 12 germany | FREQ | 3 | 83 |
| 4 | EDAF.OEDR | 24 germany | FREQ | 3 | 84 |
| 5 | EDAR.EGUN | 12 germany | FREQ | 3 | 85 |
| 6 | EDAR.HECA | 4 germany | FREQ | 3 | 86 |
| 7 | EDAR.LETO | 4 germany | FREQ | 3 | 87 |
| 8 | EDAR.LIPA | 8 germany | FREQ | 3 | 88 |
| 9 | EGUN.EDAR | 12 united kindom | FREQ | 3 | 89 |
| 10 | EGUN.LETO | 4 united kindom | FREQ | 3 | 90 |
| 11 | EGUN.LIPA | 4 united kindom | FREQ | 3 | 91 |
| 12 | FJDG.OMFJ | 12 british indian ocean territory | FREQ | 3 | 92 |
| 13 | FJDG.RJTY | 4 british indian ocean territory | FREQ | 3 | 93 |
| 14 | FJDG.WSAP | 13 british indian ocean territory | FREQ | 3 | 94 |
| 15 | GLRB.KCHS | 2 liberia | FREQ | 3 | 95 |
| 16 | HECA.EDAR | 4 egypt | FREQ | 3 | 96 |

| | | | | |
|---|---|---|---|---|
| 17 LETO.EDAF | 4 espania | FREQ | 3 | 97 |
| 18 LETO.EDAR | 4 espania | FREQ | 3 | 98 |
| 19 LETO.EGUN | 4 espania | FREQ | 3 | 99 |
| 20 LETO.LIPA | 4 espania | FREQ | 3 | 100 |
| 21 LGSA.LIRN | 4 greece | FREQ | 3 | 101 |
| 22 LICZ.KNGU | 15 italie | FREQ | 3 | 102 |
| 23 LICZ.LIRN | 12 italie | FREQ | 3 | 103 |
| 24 LIEO.LIRN | 12 italie | FREQ | 3 | 104 |
| 25 LIPA.EDAR | 8 italie | FREQ | 3 | 105 |
| 26 LIPA.EGUN | 4 italie | FREQ | 3 | 106 |
| 27 LIPA.LETO | 4 italie | FREQ | 3 | 107 |
| 28 LIRN.KNGU | 12 italie | FREQ | 3 | 108 |
| 29 LIRN.LGSA | 4 italie | FREQ | 3 | 109 |
| 30 LIRN.LICZ | 12 italie | FREQ | 3 | 110 |
| 31 LIRN.LIEO | 12 italie | FREQ | 3 | 111 |
| 32 LPLA.KWRI | 13 portugal | FREQ | 3 | 112 |
| 33 LTAG.EDAF | 12 turkey | FREQ | 3 | 113 |
| 34 OBBI.KNGU | 12 bahrain | FREQ | 3 | 114 |
| 35 OEDR.EDAF | 24 saudi arabia | FREQ | 3 | 115 |
| 36 OJAF.KDOV | 2 jordan | FREQ | 3 | 116 |
| 37 OMFJ.FJDG | 12 united arab emirates | FREQ | 3 | 117 |
| 38 OMFJ.KNGU | 15 united arab emirates | FREQ | 3 | 118 |
| 1 RJAM.RJTY | 4 japan | FREQ | 4 | 119 |
| 2 RJAW.RJTY | 4 japan | FREQ | 4 | 120 |
| 3 RJCB.RJTY | 4 japan | FREQ | 4 | 121 |
| 4 RJFF.RJTY | 4 japan | FREQ | 4 | 122 |
| 5 RJSM.RJTY | 13 japan | FREQ | 4 | 123 |
| 6 RJSM.RKJK | 13 japan | FREQ | 4 | 124 |
| 7 RJSM.RODN | 13 japan | FREQ | 4 | 125 |
| 8 RJTY.FJDG | 4 japan | FREQ | 4 | 126 |
| 9 RJTY.RJAM | 4 japan | FREQ | 4 | 127 |
| 10 RJTY.RJAW | 4 japan | FREQ | 4 | 128 |
| 11 RJTY.RJCB | 4 japan | FREQ | 4 | 129 |
| 12 RJTY.RJFF | 4 japan | FREQ | 4 | 130 |
| 13 RJTY.RJSM | 13 japan | FREQ | 4 | 131 |
| 14 RJTY.RKJK | 4 japan | FREQ | 4 | 132 |
| 15 RJTY.RKSO | 13 japan | FREQ | 4 | 133 |
| 16 RJTY.WSAP | 16 japan | FREQ | 4 | 134 |
| 17 RKSO.RJTY | 13 korea | FREQ | 4 | 135 |
| 18 RKSO.RODN | 13 korea | FREQ | 4 | 136 |
| 19 RODN.PGUA | 8 japan | FREQ | 4 | 137 |
| 20 RODN.RJSM | 13 japan | FREQ | 4 | 138 |
| 21 RODN.RKJK | 13 japan | FREQ | 4 | 139 |
| 22 RODN.RKPK | 4 japan | FREQ | 4 | 140 |
| 23 RODN.RKSO | 13 japan | FREQ | 4 | 141 |
| 24 RODN.VVNB | 1 japan | FREQ | 4 | 142 |
| 1 APLM.ASRI | 4 solomom islands | FREQ | 5 | 143 |
| 2 ASRI.APLM | 4 papua new guinea | FREQ | 5 | 144 |
| 3 PHIK.PJON | 8 hawaii | FREQ | 5 | 145 |
| 4 PHIK.PKWA | 8 hawaii | FREQ | 5 | 146 |
| 5 PHIK.PMDY | 4 hawaii | FREQ | 5 | 147 |

| | | | | |
|---|---|---|---|---|
| 6 PHIK.PWAK | 6 hawaii | FREQ | 5 | 148 |
| 7 VVNB.RODN | 1 vietnam | FREQ | 5 | 149 |
| 8 WSAP.FJDG | 13 singapore | FREQ | 5 | 150 |
| 9 WSAP.RJTY | 16 singapore | FREQ | 5 | 151 |

# Appendix E. The comparison with validation design for metamodels

# METAMODEL 1

| TREQ | FREQ | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|
| -0.5 | -0.5 | 35637443.50 | 35570398 | 67045.50 | 0.001884868 |
| -0.5 | 0.5 | 36095251.50 | 36029101.77 | 66149.73 | 0.001836008 |
| 0.5 | -0.5 | 39032908.50 | 39006052.42 | 26856.08 | 0.000688511 |
| 0.5 | 0.5 | 39490716.50 | 39423802.92 | 66913.58 | 0.001697289 |

**MSE** 3517390517.68

**MAPE** 0.152666889

# METAMODEL 2

| TREQ | FREQ | Unit Cost | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|---|
| -0.5 | -0.5 | -0.5 | 33944850.00 | 33968875.15 | -24025.15 | -0.00070727 |
| -0.5 | -0.5 | 0.5 | 37329790.00 | 37172520.86 | 157269.14 | 0.00423079 |
| -0.5 | 0.5 | -0.5 | 34402618.00 | 34404501.03 | -1883.03 | -5.47321E-05 |
| -0.5 | 0.5 | 0.5 | 37787558.00 | 37653702.52 | 133855.48 | 0.003554909 |
| 0.5 | -0.5 | -0.5 | 37340156.00 | 37249811.08 | 90344.92 | 0.002425379 |
| 0.5 | -0.5 | 0.5 | 40725096.00 | 40762115.94 | -37019.94 | -0.000908195 |
| 0.5 | 0.5 | -0.5 | 37797924.00 | 37647500.19 | 150423.81 | 0.003995586 |
| 0.5 | 0.5 | 0.5 | 41182864.00 | 41200061.52 | -17197.52 | -0.000417415 |

**MSE** 9460922924.17

**MAPE** 0.151488159

## METAMODEL3

| A | B | C | D | E | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|---|---|---|
| -0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 37389601.50 | 37384953.74 | 4647.76 | 0.000124322 |
| -0.5 | -0.5 | -0.5 | 0.5 | -0.5 | 37327287.50 | 37309861.83 | 17425.67 | 0.000467053 |
| -0.5 | -0.5 | 0.5 | -0.5 | -0.5 | 37339146.50 | 37320347.28 | 18799.22 | 0.000503726 |
| -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 37429580.50 | 37417128.21 | 12452.29 | 0.000332797 |
| -0.5 | 0.5 | -0.5 | -0.5 | -0.5 | 37356985.50 | 37343606.69 | 13378.81 | 0.000358262 |
| -0.5 | 0.5 | -0.5 | 0.5 | 0.5 | 37447419.50 | 37435996.02 | 11423.48 | 0.000305147 |
| -0.5 | 0.5 | 0.5 | -0.5 | 0.5 | 37459278.50 | 37446524.97 | 12753.53 | 0.00034058 |
| -0.5 | 0.5 | 0.5 | 0.5 | -0.5 | 37396964.50 | 37375701.48 | 21263.02 | 0.0005689 |
| 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 37569487.50 | 37541590.25 | 27897.25 | 0.000743103 |
| 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 37659921.50 | 37632022.16 | 27899.34 | 0.000741372 |
| 0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 37671780.50 | 37642691.81 | 29088.69 | 0.000772758 |
| 0.5 | -0.5 | 0.5 | 0.5 | -0.5 | 37609466.50 | 37570514.00 | 38952.50 | 0.001036784 |
| 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 37689619.50 | 37665958.98 | 23660.52 | 0.000628167 |
| 0.5 | 0.5 | -0.5 | 0.5 | -0.5 | 37627305.50 | 37594017.36 | 33288.14 | 0.000885464 |
| 0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 37639164.50 | 37605073.33 | 34091.17 | 0.000906558 |
| 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 37729598.50 | 37698521.97 | 31076.53 | 0.000824343 |

**MSE** 592121298.65

**MAPE** 0.059620838

## METAMODEL 4

| A | B | C | D | E | F | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|---|---|---|---|
| -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 34362884.50 | 34178960.52 | 183923.98 | 0.005381205 |
| -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 38028780.50 | 37682711.59 | 346068.91 | 0.009183758 |
| -0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 0.5 | 38505621.50 | 38106679.33 | 398942.17 | 0.010469088 |
| -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 35189479.50 | 34921610.80 | 267868.70 | 0.007670571 |
| -0.5 | 0.5 | -0.5 | -0.5 | 0.5 | -0.5 | 34507964.50 | 34313473.12 | 194491.38 | 0.005668076 |
| -0.5 | 0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 37991722.50 | 37647448.25 | 344274.25 | 0.00914469 |
| -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 38468563.50 | 38070328.08 | 398235.42 | 0.01046052 |
| -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -0.5 | 35334559.50 | 35055154.14 | 279405.36 | 0.00797045 |
| 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 40190680.50 | 40189305.87 | 1374.63 | 3.42039E-05 |
| 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | 37056676.50 | 36961550.51 | 95125.99 | 0.002573647 |
| 0.5 | -0.5 | 0.5 | -0.5 | 0.5 | -0.5 | 37533517.50 | 37232519.89 | 300997.61 | 0.008084266 |
| 0.5 | -0.5 | 0.5 | 0.5 | -0.5 | 0.5 | 41017275.50 | 40829938.79 | 187336.71 | 0.004588219 |
| 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 40335760.50 | 40334448.91 | 1311.59 | 3.25179E-05 |
| 0.5 | 0.5 | -0.5 | 0.5 | -0.5 | -0.5 | 37019618.50 | 36928005.86 | 91612.64 | 0.002480844 |
| 0.5 | 0.5 | 0.5 | -0.5 | -0.5 | -0.5 | 37496459.50 | 37198895.76 | 297563.74 | 0.007999263 |
| 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 41162355.50 | 40975607.11 | 186748.39 | 0.00455755 |
| | | | | **MSE** | | 65254366356.58 | | | |
| | | | | **MAPE** | | 0.601867938 | | | |

## METAMODEL 5

| A | B | C | D | E | F | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|---|---|---|---|
| -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 35686884.50 | 35603709.57 | 83174.93 | 0.002336131 |
| -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 39185830.50 | 39105623.83 | 80206.67 | 0.002051026 |
| -0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 0.5 | 39268800.50 | 39283122.29 | -14321.79 | -0.000364579 |
| -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 35948424.50 | 35928958.81 | 19465.69 | 0.000541783 |
| -0.5 | 0.5 | -0.5 | -0.5 | 0.5 | -0.5 | 35753341.50 | 35692196.57 | 61144.93 | 0.001713118 |
| -0.5 | 0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 39193679.50 | 39094865.02 | 98814.48 | 0.002527556 |
| -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 39276649.50 | 39247895.73 | 28753.77 | 0.000732619 |
| -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -0.5 | 36014881.50 | 35995289.99 | 19591.51 | 0.00054428 |
| 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 39176704.50 | 39148122.13 | 28582.37 | 0.000730108 |
| 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | 35914936.50 | 35878948.29 | 35988.21 | 0.001003045 |
| 0.5 | -0.5 | 0.5 | -0.5 | 0.5 | -0.5 | 35997906.50 | 35919524.76 | 78381.74 | 0.002182149 |
| 0.5 | -0.5 | 0.5 | 0.5 | -0.5 | 0.5 | 39438244.50 | 39371476.71 | 66767.79 | 0.001695842 |
| 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 39243161.50 | 39218227.69 | 24933.81 | 0.000635771 |
| 0.5 | 0.5 | -0.5 | 0.5 | -0.5 | -0.5 | 35922785.50 | 35894338.53 | 28446.97 | 0.00079252 |
| 0.5 | 0.5 | 0.5 | -0.5 | -0.5 | -0.5 | 36005755.50 | 35912366.74 | 93388.76 | 0.002600462 |
| 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 39504701.50 | 39416932.73 | 87768.77 | 0.002226677 |
| | | | | **MSE** | | 3701143541.90 | | | |
| | | | | **MAPE** | | 0.137178178 | | | |

# METAMODEL 6

| A | B | C | D | E | F | G | H | J | K | L | Y-hat | Real Y | Error | Error/Real Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 34288149.00 | 33968875.15 | 319273.85 | 0.009399012 |
| -0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 38215665.00 | 37744120.93 | 471544.07 | 0.012493179 |
| -0.5 | -0.5 | -0.5 | 0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 34866520.00 | 34558417.42 | 308102.58 | 0.008915413 |
| -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 37987636.00 | 37521097.16 | 466538.84 | 0.01243404 |
| -0.5 | -0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 38544333.00 | 38064077.91 | 480255.09 | 0.012617016 |
| -0.5 | -0.5 | 0.5 | -0.5 | 0.5 | -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | 35284619.00 | 34970398.25 | 314220.75 | 0.008985335 |
| -0.5 | -0.5 | 0.5 | 0.5 | -0.5 | -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 38857094.00 | 38396491.76 | 460602.24 | 0.011995946 |
| -0.5 | -0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | -0.5 | -0.5 | -0.5 | -0.5 | 35322200.00 | 35013701.06 | 308498.94 | 0.008810806 |
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# REPORT DOCUMENTATION PAGE

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**13. ABSTRACT** *(Maximum 200 words)*

The methodology of Johnson, Bauer, Moore, and Grant can be applied to large scale linear programming models. A methodology for optimality analysis of linear programs was developed to create metamodels using response surface methodology techniques such as experimental design and least squares regression.
A metamodel consists of a simple equation which is able to predict the optimal objective function value of a linear program. What is needed is some large scale application of the techniques to verify how accurate they are. In the research, I plan to use the large scale LP model, STORM. I use the "Hot Start" idea for the efficiency of STORM program calculation. The developed metamodels of the large scale LP can provide some useful information about the relationships between the objective function value and the right-hand-side vector and coefficients of the objective function (unit cost vector) by varying the right-hand-side vector and unit cost vector.

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